

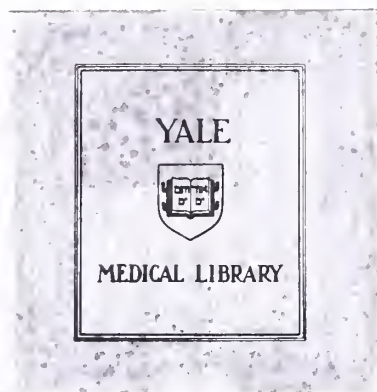


BYPASS SURGERY FOR
LEFT MAIN CORONARY ARTERY DISEASE:
REDUCTION IN MAJOR OPERATIVE COMPLICATIONS
WITH PREOPERATIVE INSTITUTION OF
INTRA-AORTIC BALLOON COUNTERPULSATION



STEVEN R. TAHAN

1979





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BYPASS SURGERY FOR LEFT MAIN CORONARY ARTERY DISEASE:
REDUCTION IN MAJOR OPERATIVE COMPLICATIONS WITH
PREOPERATIVE INSTITUTION OF INTRA-AORTIC BALLOON COUNTERPULSATION

A thesis submitted to the faculty of the
Department of Internal Medicine,
Yale University School of Medicine in
partial fulfillment of the requirements
for the degree of Doctor of Medicine

Steven R. Tahan

February, 1979

New Haven, Connecticut

For my family, who have never failed to point out
the positive in life's experiences.

Deepest appreciation and thanks to Dr. Rene A.

Langou for earnest support and interest in me

throughout medical school, and for guidance and

encouragement for this work.

ABSTRACT

This paper reviews the prognosis of left main coronary artery (LMCA) obstruction and evaluates experience to date of medical and surgical therapy. Physiologic principles of intra-aortic balloon counterpulsation are discussed, and applications and complications of clinical usage reviewed. We report on the operative results of 91 consecutive patients with greater than or equal to 50% stenosis of the LMCA undergoing bypass surgery at Yale-New Haven Hospital from July 1975 through December 1977. Incidence of operative death and perioperative myocardial infarction is analyzed for subgroups of patients assisted and unassisted with counterpulsation prior to surgery. The preoperative risk profile of 36 patients receiving the intra-aortic balloon pump (IABP) is compared with that of 56 patients not receiving the pump to evaluate possible grouping biasing. Of 26 demographic, clinical, hemodynamic and operative descriptors, the only parameters found to differ significantly between the groups were the severity and pattern of anginal symptoms prior to admission. The assisted group had a greater proportion of patients with New York Heart Association Class IV angina (80% vs. 45%) and a higher percentage with unstable angina (37% vs. 7%). The assisted group, despite presenting poorer presurgical clinical symptoms, had a significantly lower incidence of perioperative infarction (23% vs. 3%, $p < 0.05$) and a reduced, but not statistically significant, rate of operative death (11% vs. 6%). Additive properties for operative risk were established for the presence of additional disease of the right coronary artery and not using the IABP, as well as for prolonged duration of cardiopulmonary bypass and not assisting with counterpulsation. Vulnerable periods during bypass operations are discussed and the possible role of the IABP in ameliorating myocardial

vulnerability during these phases reviewed. It is suggested that the intra-aortic balloon pump can be of significant benefit when used preoperatively for patients with left main stenosis going to bypass surgery.

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INTRODUCTION

Coronary artery disease (CAD) is estimated to affect more than 5 million individuals and annually account for greater than 650,000 deaths, or over 37 percent (%) of the total mortality in the United States (1-4). The natural history of symptomatic CAD can include angina pectoris of varying severity, myocardial infarction (MI), congestive heart failure, arrhythmias, and increased risk of death. The overall annual mortality of cardiac origin after clinical diagnosis of angina pectoris is currently 3 to 13% with a 5-year mortality of 15 to 44% (5-13). At particularly high risk is the subgroup of patients with significant occlusive disease of the left main coronary artery (LMCA) comprising approximately 7 to 10% of patients with angina pectoris (8,14-23). The risk of death in the first year following diagnosis in this subgroup is 15 to 30%, and in the second year an additional 10 to 15% with a 5-year cardiac mortality rate of 50 to 60% (8,14-26). Early surgical intervention has, thus, become increasingly common for this disease, and many centers have reported prolonged survival and alleviation of symptoms in surgically treated groups (17,22,25,27-33).

Obstruction of the left main coronary artery is itself a significant risk factor for operative mortality and for the occurrence of myocardial infarction during or in the period immediately following bypass (8,17,21,22,30,33-35). Operative mortality has been reported to be two to five fold higher and perioperative infarction over 50% more common in patients with significant left main narrowing. Such experience is of obvious

concern to cardiologists and surgeons who must weigh the benefit against risk of surgery and make recommendations to patients in this category. .

The intra-aortic balloon pump (IABP) has been used clinically since 1968 to support the circulation and alleviate myocardial ischemia in a variety of cardiac and noncardiac disorders (36-40). Experience with prophylactic intra-aortic balloon counterpulsation for cardiac surgery has demonstrated a value for its use in patients with serious left ventricular dysfunction, impending myocardial infarction, or both (41-43). Recent reports suggest, in addition, a possible benefit of using the IABP prophylactically in patients with left main disease undergoing bypass surgery (23,30,44). This study will evaluate preoperative intra-aortic balloon counterpulsation for patients undergoing aorto-coronary bypass grafting for left main obstruction in recent experience at Yale-New Haven Hospital. We prospectively collected data on 91 consecutive patients having bypass surgery for main left coronary stenosis from July 1975 through December 1977 to determine if using the IABP had any effect on the incidence of operative deaths and perioperative myocardial infarction.

The history of left main coronary (LMCA) stenosis began in 1912 when James Herrick wrote the first clinical description of acute myocardial infarction (45). Herrick described a 55 year old male patient dying in cardiogenic shock after a period of 52 hours, who at autopsy was found to have total occlusion of the LMCA by a thrombus overlying an area of atherosclerotic narrowing. There was associated extensive necrosis of the left ventricle.

The main left coronary artery carries the primary blood supply to the free wall and apex of the left ventricle as well as to the interventricular septum (46). Obstructive disease of the short segment proximal to the bifurcation of the main stem into the left anterior descending (LAD) and left circumflex (LCF) arteries thus endangers all but the inferior and posterior surfaces of the ventricle.

Appreciation of the ominous nature of LMCA stenosis was based primarily on autopsy documentation of obstruction of the LMCA in patients dying suddenly until 1972, when Cohen and associates published the first clinical and catheterization studies of clinical correlates and prognosis of LMCA disease (47). Fifty percent of their patients with LMCA stenosis treated nonsurgically died within an average follow-up period of 25 months. The mortality of the surgical group was also very high (29%), in addition to a high mortality encountered at the catheterization procedure itself (16%). While the numbers in this study were small and angiographic and surgical technique non-refined, the paper outlined several important areas

for subsequent study in this group: determining the incidence of LMCA disease among patients with coronary disease, quantitating prognosis, recognizing and reducing the risk of coronary angiography, determining if specific historical, physical, or laboratory features might distinguish LMCA lesions prior to catheterization, and evaluating methods of therapy.

Incidence of LMCA Disease

Since 1972 many centers have published the results of their catheterization experience with specific reference to left main lesions, outlining angiographic correlates to clinical data and follow-up history. Recognizing the heterogeneity of population groups resulting from referral patterns, variations in technique, different follow-up periods, and varying methods of presentation and analysis, we find it difficult to make direct comparisons among the studies and come up with definitive statements regarding aspects of left main disease. Strong patterns, however, do emerge and in the table below we have listed combined data to provide an overall idea of the expected parameters of LMCA lesions.

Table 1 shows the incidence of stenotic lesions of greater than 50% of the LMCA as reported by various investigators among patients undergoing coronary angiography (8,14-17,19,20,22,26).

A weighted average has been calculated and standard deviation for the populations noted. The range of incidence of LMCA is 2.6% to 11.1% in the reports with an average of approximately 7%.

Table 1. Incidence of $\geq 50\%$ LMCA Narrowing Among Patients Undergoing Angiography

Reference	Investigators	No. of Patients	% of pts. undergoing angiography with $\geq 50\%$ LMCA stenosis
8	Bruschke et al, 1973	590	6.3
14	Cohen and Gorlin, 1975	500	8.2
15	Proudfit et al, 1967	1000	5.9
16	Takaro et al, 1976 VA Randomized Study	1015	11.1
17	Farinha et al, 1978	4196	7.0
19	Khaja et al, 1974	695	4.0
20	DeMots et al, 1975	2450	2.6
22	Oberman et al, 1976	3081	5.8
26	Conley et al, 1978	3498	9.0
TOTAL:		17,025	6.6% $\sigma=2.3$

$$\sigma = \sqrt{\frac{\sum_{i=1}^n x_i^2 - n\bar{x}^2}{n}}$$

It is difficult to assign a precise interpretation to this figure regarding the prevalence of LMCA disease among patients with coronary disease (CAD) in general, as these series reported frequency as a function of all patients undergoing angiography ^{pro-}_a portion of whom did not have CAD. The prevalence of LMCA disease in the CAD population is thus, probably somewhat higher than 7%. In the Cleveland Clinic series, for example, of the 1000 patients catheterized, only 588 had angiographic evidence of coronary artery obstruction (15). Ten percent of these 588 patients had significant left main obstruction.

Prognosis of LMCA Obstruction

In evaluating the available data concerning the natural history of LMCA disease, we chose to study those reports which had no surgical patients and those with randomized non-biased groupings in order to eliminate any selection factor associated with choosing surgical candidates. These studies are combined in Table 2: (8,14,16,18,20,25-27,32).

Table 2. Prognosis After Diagnosis of >50% Obstruction of LMCA

Reference	Investigator	No. of Pts.	Cumulative Mortality Rate (%)							
			6 mo.	1 yr.	18 mos.	2 yr.	3 yr.	4 yr.	5 yr.	
8	Bruschke et al, 1973	37		29		40	47	57	57	
14	Cohen and Gorlin, 1975	17				44	51	71		
16	Takaro et al, 1976 VA Randomized Study	53	20	29	32	32	33			
18	Lavine et al, 1972	9	33							
20	DeMots et al, 1975	19	10	16	37	47	57	74		
25	Talano et al, 1975	51	38	48	48	61				
26	Conley et al, 1975	163	15	21		36	50			
27	Lim et al, 1975	141		21.9		34.7	43		51	
32	Campeau et al, 1978	114		7		21	36	40	50	
Total No. Patients			604	295	578	123	595	544	187	292
Average:				20.1%	21.9%	39.4%	35.4%	43.7%	49.6%	51.3%
σ:				9.0	10.6	7.4	10.2	6.6	13.0	2.2

Inherent in these data is variability among population groups with respect to degree of LMCA narrowing, left ventricular dysfunction, involvement of the right coronary artery, and other clinical parameters. While this table is an oversimplification of the prognosis following diagnosis of LMCA obstruction (vide infra), indeed the risk of death is clearly very high. The mean mortality for patients with $\geq 50\%$ obstruction of the LMCA following diagnosis is 20% at 6 months, 22% at one year, 35% at 2 years, 44% at 3 years, and 51% at 5 years.

While the studies listed in Table 2 have excluded from analysis known catheterization related deaths, the high mortality in the first 6 months may bear some relationship to the catheterization procedure itself, as many centers in the late 1960's and early 70's reported a high mortality among patients with this lesion during and in the first month following angiography (17-20,47,48). The early study by Cohen et al (47) of 32 patients catheterized from January 1964 to May 1971 with LMCA stenosis reported 5 catheterization-related deaths (16%), 3 of whom had cardiac arrest immediately after introduction of the catheter into the left coronary ostium and 2 suffering myocardial infarction during the procedure and succumbing in the following two weeks. In their follow-up report in 1975 (14) there was only 1 catheterization-related death of 41 patients with LMCA lesions catheterized from May 1971 to November 1973 (2.4%). They attributed this dramatic improvement to a change in technical approach to patients suspected of having main left lesions. They found that the best initial approach was to opacify the left coronary sinus

non-specifically and, if further definition is necessary, to slowly and carefully advance a preformed catheter into the left coronary ostium, leaving the catheter in place only for the injection of dye. Several other workers reported similarly high mortalities associated with angiography prior to such technical changes (17,18,47-49). Others, particularly in more recent reports had a mortality of catheterization of 2% or less (8,18-21,28,29,50).

The cause of myocardial infarction or death resulting from coronary arteriography is not readily apparent at post-mortem examination. Bassan and associates, however, (51) made measurements of peripheral coronary pressure through an arteriography catheter in the left coronary ostium and simultaneous coronary sinus blood flow in several patients with CAD. Only the patient with LMCA stenosis experienced a dramatic fall in flow and pressure when the angiographic catheter was introduced into the ostium. It was concluded that coronary arteriography might well jeopardize a pre-existing tenuous hemodynamic situation and thus lead to a high catheterization-related mortality rate.

Comparison to Overall Group with Coronary Artery Disease

Prior to studies specifically relating to LMCA disease, extensive investigations had been made to document the natural history of coronary disease in general. For the most part these studies consisted of patient populations with angina pectoris treated medically and followed for one to seven years in the period prior to the advent of bypass surgery at the

involved institution. Efforts to relate mortality rate to risk factors, many of which are interrelated, were extensively made. In all of these reports, prognosis appears to relate most strongly to the number of hemodynamically compromised coronary vessels ($\geq 70\%$ luminal narrowing) (8-13). A detailed analysis of these studies is not within the scope of this paper, but a summary of combined results is displayed in Table 3 for comparison to the left main subgroup. Mean annual mortality for patients with single vessel disease was 2.8% in these reports. Patients with double and triple vessel involvement had a much poorer prognosis with annual mortality rates of 7.7% and 13.0%, respectively.

When these figures are compared to the cardiac mortality for left main stenosis, several features are salient. The prognosis for LMCA disease is poorer than for single and for double vessel obstruction at least up to 5 years after diagnosis. Expected mortality for LMCA obstruction in general is also higher than for triple vessel disease for the first 2 to 3 years following diagnosis, at which point the expected mortality for the two groups is roughly equal. We caution that these statements are oversimplifications, as other factors influencing prognosis have not been considered.

Table 3.

Reference	Investigator	No. of Patients	Cardiac Deaths	Average Follow-up (Months)	Annual Mortality Rate (%)
SINGLE VESSEL DISEASE					
8	Bruschke et al, 1973	202	29	84	2.6
22	Oberman et al, 1972	46	2	20	2.6
10	Lichtien et al, 1972	83	8	32	3.6
11	Moberg et al, 1972	84	17	84	2.9
12	Slagle et al, 1972	20	1	48	4.0
13	Friesinger et al, 1970	32	1	54	0.7
TOTAL		<u>467</u>	<u>58</u>	<u>65</u>	<u>2.8</u> $\sigma=0.71$
DOUBLE VESSEL DISEASE					
8	Bruschke et al	233	88	70	6.4
22	Oberman et al	50	13	22.7	13.7
10	Lichtien et al	62	11	32.0	6.7
11	Moberg et al	82	36	84.0	6.3
12	Slagle et al	<u>26</u>	<u>5</u>	<u>15.0</u>	<u>15.4</u>
TOTAL		453	153	59	7.7 $\sigma=2.9$
TRIPLE VESSEL DISEASE					
8	Bruschke et al	118	65	84	9.6
22	Oberman et al	52	14	19.3	16.7
10	Lichtien et al	86	29	32.0	12.6
11	Moberg et al	34	24	84.0	10.1
12	Slagle et al	<u>48</u>	<u>12</u>	<u>15.0</u>	<u>20.0</u>
TOTAL		338	144	51	13.0 $\sigma=3.73$

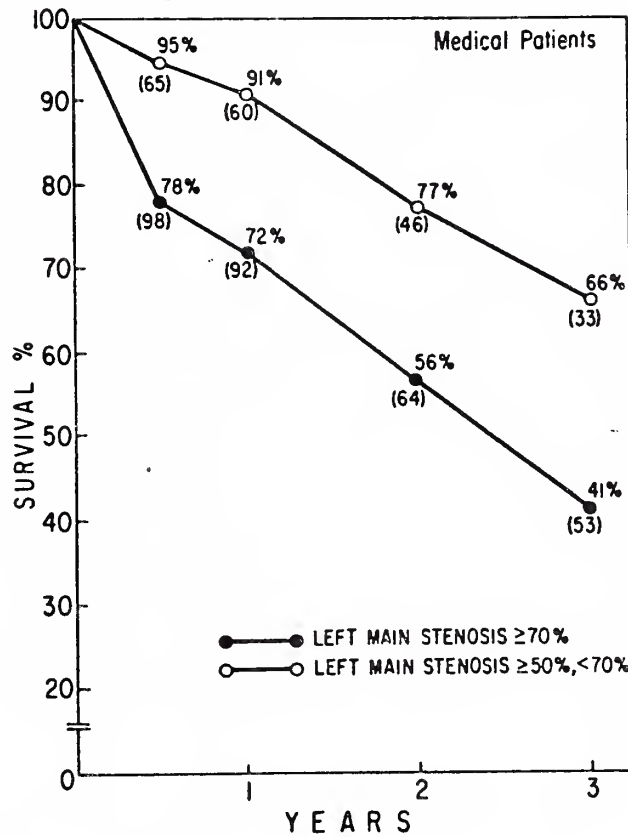
Prognostic Spectrum of Left Main Stenosis:

Several investigators have attempted to subdivide the left main group into categories with different prognoses (16,26,27). Takaro and co-workers (16) in interpreting the results of the VA cooperative randomized study in 1976 characterized a "high risk" group (poorer prognosis without surgery and higher surgical risk) consisting of patients with left main stenosis plus right coronary obstruction of $\geq 70\%$, plus some abnormality of left ventricular function. Left ventricular function was considered "abnormal" if any one of the following parameters was present: cardiac enlargement, abnormality of left ventricular contraction, elevation of left ventricular end-diastolic pressure (LVEDP) above 15mm Hg, or left ventricular ejection fraction (EF) $< 50\%$. There was a 30% mortality rate in this group of 30 medically treated "high risk" patients in the first six months, 40% mortality by 12 months, and 45% by 18 months, compared to 20%, 29%, and 32% mortality in the same intervals for the overall group of 53 medically treated LMCA patients.

Other authors have attempted to refine prognostic ability based on extent of LMCA narrowing. Conley and colleagues (26) followed long-term survival in 163 consecutive medically treated patients with 50 to 70% left main stenosis and 98 patients with 70% or greater LMCA stenosis and calculated survival rates up to 3 years. The vast majority of patients in both groups had three-vessel disease. Figure 1 is taken from their report, illustrating a statistically significant higher cumulative survival rate among patients with 50 to 70% stenosis compared to those with $\geq 70\%$

narrowing of the LMCA.

Figure 1: (from Conley et al: Circulation 57: 950, 1978)



Three year survivals were found to be 66% for the group with less severe obstruction compared to 41% ($p < .05$). The authors, in addition, outlined baseline characteristics they found to be significant predictors of one year mortality among patients with $\geq 70\%$ left main stenosis: history of congestive heart failure (CHF), chest pain at rest, cardiomegaly on chest x-ray, ST-T wave changes on the resting electrocardiogram (ECG), and catheterization parameters indicative of left ventricular dysfunction

(abnormal left ventricular contraction, LVEFP >15mm Hg, and arterio-venous oxygen difference >5.5 vol.%):

Table 4. (From Conley MJ, et al: Circulation 57: 950, 1978)

	One year survival in pts with <u>≥ 70%</u> <u>LMCA obstruction</u>	
	<u>Present</u>	<u>Absent</u>
History of congestive heart failure	50%	81%
Chest pain at rest (NYHA Class IV)	62%	85%
Resting ST-T wave changes	61%	83%
Cardiomegaly on chest x-ray	50%	78%
Abnormal left ventricular contraction	61%	95%
Left ventricular end-diastolic pressure >15mm Hg	50%	81%
Arteriovenous oxygen difference >5.5 vol%	50%	80%

They then characterized low and high risk subgroups of patients with ≥70% LMCA obstruction based on four noninvasive descriptors: CHF, chest pain at rest, cardiomegaly on chest x-ray, and ST-T wave changes on resting ECG. Thirty-five patients had none or only one of these descriptors and were considered "low risk", and 63 had more than 1 descriptor present and were considered "high risk". Survival at each interval up to 3 years was significantly higher for the low risk subgroup than for the high risk subgroup with 1 year survivals of 97% and 59% and three-year survivals of 74% and 25%, respectively.

Among the catheterization parameters studied, patients with abnormal left ventricular contraction pattern, elevated arteriovenous oxygen difference, and elevated left ventricular end-diastolic pressure, had significantly lower one-year survivals.

Another large series of medically treated patients with LMCA disease was reported in 1975 by Lim and associates (27). They also examined the relationship between degree of left main narrowing and long-term survival, but were unable to demonstrate a significant correlation. This is in disagreement with the results of Conley et al and may be due to the inadvertent patient selection by Lim et al who excluded all medically treated patients who underwent surgery within five years of the date of catheterization. These patients could possibly have been "lower risk", with only 50 to 70% stenosis and had a lower mortality. The authors did, however, identify a number of prognostically important factors for 5-year survival including severity of angina pectoris, history of congestive heart failure, electrocardiographic abnormalities, evidence of left ventricular hypertrophy, three-vessel disease, and decreased left ventricular contractility. These findings, like the results of Cohen et al (14), parallel the descriptors of the Conley study (26).

Noninvasive Indicators of LMCA Disease

In response to the high risk associated with catheterization for patients with LMCA stenosis, effort has been made to identify noninvasive descriptors that might suggest the presence of this lesion. Cohen and Gorlin (47) examined a large number of historical, physical, and laboratory factors including history of myocardial infarction, hypertension, the nature, duration, radiation, severity and pattern of angina pectoris, symptoms associated with chest pain such as dyspnea and faintness, carbohydrate and lipid abnormalities, electrocardiographic evidence, and, where possible, the double Master's two-step exercise test (52,53). They found no specific historical, physical or laboratory feature that differentiated the 32 patients in the LMCA subgroup from the larger population of CAD patients. A marked ischemic response to the double Master's test, however, was seen in 82% of the LMCA patients, with more than 2mm R-ST segment depression at adequate rate response. This compares with reports of 34% of patients with CAD, most commonly triple-vessel disease, exhibiting this degree of response (54). While there were false positives, their results suggested that all patients with marked ischemic response to the Master's test are suspect for either LMCA disease or proximal disease of all three major coronary vessels. Kisslo and co-workers confirmed these findings (21), reporting that in patients with three-vessel involvement, the additional presence of a LMCA lesion significantly increases the likelihood of a positive exercise test. Khaja et al (19) reported a similarly

high percentage of LMCA patients with markedly ischemic exercise responses (77%).

The intermediate coronary syndrome and myocardial infarction have not been found to be more common in patients with LMCA lesion despite the large amount of myocardium endangered. Several studies of patients with the intermediate syndrome report only 11-12% frequency of LMCA stenosis (55-57). This is only slightly higher than the above noted frequency of LMCA stenosis in the general CAD population.

The diagnosis of LMCA disease, thus, ultimately depends upon coronary angiography, but may be suggested by a markedly ischemic exercise response.

Treatment of LMCA Obstruction: Medical vs Surgical

Extensive investigations have been attempted by many authors comparing survival rates of patients with significant LMCA stenosis treated medically and surgically (16-18,20-23,25,28,33,50). Table 5 displays a summary of the results of major studies. Interpretation of the figures is indeed difficult as many of the reports contain strong biasing resulting from selection of surgical candidates, inadequate or selective patient follow-up, or a combination of these problems. In addition heterogeneity of patient populations, variation in degree of left main obstruction, involvement of the right coronary artery (RCA), variation in surgical technique, and refinement in surgical ability over the years makes comparative analysis among reports from different centers of questionable validity.

Table 5. Cumulative Survival After Diagnosis: Medical Versus Surgical Therapy

Ref.	Investigator	Med/ Surg	Selection Biasing	No. of Pts.	6 mo.	1 yr.	18 mo.	2 yr.	30 mo.	3 yr.	4 yr.	5 yr.
16	Takaro et al VA Study 1976	Med Surg	No	53 60	80 88NS	71 85NS	68 85<.05	68 85<.05	65 85<.02	65 81NS		
17	Farinha et al 1978	Med Surg	Yes	30 267				91		89	50 86	
20	DeMots et al 1975	Med Surg	No	19 28	89 82NS	85 78NS	63 78NS	53 36NS		43 32NS	26	
22	Oberman et al 1976	Med Surg	No	24 141	83 92	73 89	65 86	65 86	p<0.02			
25	Talano et al 1975	Med Surg	Yes	32 89	70 88	60 82	60 80	45 78				
28	Zeft et al 1974	Med Surg		NO MEDICAL GROUP 56	89	86						
29	Suap et al 1975	Med Surg	Yes	11 19		55	89					
31	McConahay et al 1976	Med Surg	Yes	30 146	NOT FOLLOWED			92		92		
32	Campeau et al 1978	Med Surg	Yes	114 197		92 90		79 89		69 86	60 85	50 78

p value listed in table where known.

NS= not significant ($p \geq 0.05$).

Farinha et al (17) compiled a large series of impressive surgical results with a 4-year survival reportedly 86%. In their group of 297 patients with left main narrowing of $\geq 50\%$, 30 patients did not undergo the bypass procedure either because they died at angiography, had extensive involvement of the distal coronary tree, precluding surgery, refused surgery, or had other contraindications. The non-surgical group had a 50% 5-year survival, which is consistent with the results of others described above. Talano et al (25) attempted to avoid biasing by eliminating from the comparative medical group those patients considered inoperable. Of risk factors compared for the operable and surgical groups, however, two were found more prevalent in the medically treated "operable" group than the surgical group: proximal RCA obstruction (71% vs 53%) and left ventricular contraction abnormalities (57% vs 44%). Their results show improvement in survival for the surgical groups, the significance of which is uncertain. Sung and colleagues (29) published results of 19 LMCA patients undergoing bypass grafting showing an 89% surviving percentage at 18 months compared to 55% for the 11 nonsurgically treated patients. The authors admit a surgical biasing in this study and subdivide their nonsurgical group into those "suitable" and "unsuitable" for surgery based on adequacy of distal coronary vasculature. A high percentage of those patients felt to be unsuitable for surgery died in the first year (67%), and a comparison of patients considered surgical candidates treated medically with those treated surgically yielded no difference in survival rates for the two groups. Similarly, Campeau et al (32)

published the results of a large series of LMCA patients treated medically and surgically showing significant improvement in long-term survival with surgery. Their unoperated cohort, however, had lower ejection fractions and higher left ventricular end-diastolic pressures than the operated group.

Three studies approached the evaluation of treatment for left main obstruction using comparable groupings (16,20,22). Takaro et al (16) in the VA prospectively randomized study compared a group of 53 LMCA patients treated medically to 60 LMCA patients treated surgically in 30 cooperating VA hospitals. The treatment groups were established prospectively and had equal distributions of all historical, physical, laboratory, angiographic, and hemodynamic parameters. Statistically significant cumulative survival rate differences were found at 18 months, 2 years, and 20 months. Surgical patients at these times had 85%, 85%, and 85% surviving percentage, respectively, compared to 68%, 68%, and 65% in medically treated patients. The results of Oberman et al from the University of Alabama (22) show similarly improved survival rates for surgically treated patients up to 2 years after surgery in comparable groupings. In their comparison the authors avoided biasing by eliminating from consideration patients judged unsuitable for operation because of diffusely hypokinetic ventricles, ejection fractions of less than 0.20, or diffuse distal disease of the three major coronary arteries. DeMots et al (20), in analyzing the results of a series of LMCA patients treated medically and surgically were

able to eliminate surgical biasing in a similar way. They, however, found no significant improvement in long-term survival with surgery.

Attempts have been made to identify a subgroup among patients with LMCAD that might benefit more definitely from surgical management. Takaro et al (16) identified a "high risk" subgroup with poorer prognosis than the overall LMCAD group when treated medically. As described above, these were patients with significant LMCA obstruction plus significant right coronary artery obstruction plus some abnormality of left ventricular function. A comparison of survival curves of 30 high risk patients treated medically and 34 high risk patients treated surgically consistently indicated statistically significant higher survival with surgical management. At 6 months, 12 months, 24 months, and 36 months after surgery or diagnosis, the surgical group had 88%, 88%, 88%, and 83% surviving percentage, respectively, compared to 70%, 60%, 55%, and 55% at the same follow-up intervals for the medical group. Even discounting left ventricular function, patients in this study having both a left main lesion and significant right coronary arterial disease fared better surgically.

Similar results were reported by Campeau et al (32) who found a significantly higher survival rate with surgical treatment for LMCA patients with additional RCA obstruction ("triple-vessel disease") than for medical treatment. Their group of LMCA surgical patients who did not have significant RCA disease did not have a statistically significant increase in survival.

While the quality of work in this area has been variable, it appears likely that surgery does improve long-term survival for patients with LMCA lesions. If disease of the RCA is additionally present, surgery is more likely to be of value in prolonging life. Furthermore, if there is RCA obstruction plus some degree of left ventricular dysfunction, surgery will most likely be of benefit for prolonging survival.

Assessment of the Quality of Life:

The proportion of patients free from angina pectoris, congestive failure, or myocardial infarction was consistently higher in all reports for survivors of surgery, as compared to medically managed patients (16-18, 20-23, 25, 28, 33, 50). In surviving surgically treated patients whose angina was not completely relieved, the relative frequency and severity of symptoms was reportedly decreased for the majority of patients in all studies. In addition, increase in exercise tolerance has been reported for survivors of surgery for LMCA obstruction. McConahay et al (31) reported that 74% of 54 patients having abnormal preoperative stress tests converted to normal after surgery. Zeft et al (28) also reported improvement in exercise tolerance using supine bicycle ergometry in a number of their patients. Their results are difficult to interpret, however, as only 6 of 56 LMCA patients undergoing bypass surgery were tested both pre- and post-operatively, all 6 showing marked improvement after surgery.

Operative Risk for LMCA Disease: Mortality and Perioperative Myocardial Infarction:

Early results of surgery for LMCA obstruction showed a very high operative mortality for this subgroup. Surgical mortality ranged in many centers from 10 to 31% for LMCA patients before refinements in technique were instituted (Table 6).

Table 6. Early Results for Operative Mortality in LMCA Disease

<u>Reference</u>	<u>Investigator</u>	<u>Dates of Surgery</u>	<u>No. of Pts.</u>	<u>Operative Mortality (%)</u>
16	Takara et al,	1970 - 1972	20	25
20	DeMots et al	1967 - 1974	26	15.4
28	Zeft et al	1970 - 1971	56	10.7
57	Cooley et al	1970 - 1972	82	25.6
58	Oldham et al	1969 - 1972	<u>26</u>	<u>31</u>
	TOTAL:		210	
	AVERAGE:			21%
	σ :			7.4

With increasing surgical experience and technical improvements operative morbidity and mortality improved steadily since the early 70's for bypass procedures in general and markedly for bypass procedures in patients with left main obstruction (57-67). Table 7A summarizes the results of operations performed in recent years and presents approximate current estimates of expected operative mortality and incidence of perioperative myocardial infarction (MI) in the LMCA subgroup. For comparison, a summary of reported results for surgical mortality and perioperative

MI rates in major centers for the overall CAD patient population is presented in Table 7B.

Table 7A: Risks of Bypass Surgery for LMCA Stenosis (combined procedures excluded)

Ref.	Investigator	Dates of Surgery	No. of Pts	Operative Mortality (%)	Perioperative MI (%)
14	Cohen et al	1971-1973	41	11	
16	Takara et al (VA Coop Study)	1970-1971 1971-1974	20 45	25 7	12.3
17	Farinha et al	1970-1975	267	7	7.9
22	Oberman et al	1966-1975	149 87	3.0	6.9*
25	Talano et al	1968-1974	89	11	
28	Zeft et al	1970-1971	56	10.7	
29	Sung et al	1972-1974	19	5.3	
30	Garcia et al	1974-1976	18	11	
31	McConahay et al	1971-1975	146	1.4	
32	Campeau et al	1972-1976	144	6.2	
35	Langou et al	1974-1975	19		37
TOTAL NO. OF PATIENTS:				994	438
AVERAGE:				6.6%	8.0%
σ :				4.1	6.6

*figure does not include operative deaths who infarcted.

Table 7B: Risks of Bypass Surgery for CAD-Overall Population
(combined procedures excluded)

Ref.	Investigator	Dates of Surgery	No. of Pts	Operative Mortality (%)	Perioperative MI (%)
59	Cooley et al	1971-1972	1289	7.1	14.1
62	Sheldon et al	1974	1947	1.6	4.7
63	Anderson et al	1973	134	1.5	
65	Kouchoukos et al	1970-1975 1974	1590 315	1.6	3.5
66	Morris et al	1970-1971	480	6.5	10
67	Brymer et al	1974-1975	151	4.6	
68	Geha et al	1973-1974 1971-1974	128 213	4	5.2*
69	Hall et al	1972 1968-1972	217 1105	5.1	14.1
70	Langou et al	1974-1975	168	4.7	23
TOTAL NO. OF PATIENTS:				5988	5517
AVERAGE:				3.5%	9.7%
σ :				2.4	5.0

*Figure does not include operative deaths who infarcted.

The average operative mortality in these series of patients with LMCA stenosis was 6.6% with a range of 1.4% to 11% in various centers performing bypass operations since 1971. This compares with 3.5% operative mortality rate for the CAD population in general for operations performed since 1971 in major centers (range: 1.5 to 7.1%).

It is difficult to define the precise role of the left main lesion itself in influencing this two-fold increase in risk for operative mortality. Studies addressing factors correlating with mortality for bypass procedures have identified 4 high risk predictors and 6 factors of lesser importance for operative mortality. Mundth and Austen (71) in an excellent review of this subject found a consistently high correlation in the literature of left ventricular (LV) dysfunction, recent myocardial infarction, combined surgical procedures, and experience and skill of the surgical team to operative mortality rate (57,64-66,71-78). Less consistent correlation with mortality was found for age, severity of angina, the number of vessels involved, the number of vessels grafted, previous (old) myocardial infarction, and acute myocardial ischemia (57,64-66,71-79). (Table 8).

Table 8: (after Mundth and Austen: N Engl J Med 293: 13, 1975.)

Risk Factors for Operative Mortality in Coronary Bypass Grafts

<u>High Risk Correlates</u>	<u>Factors of Lesser Influence</u>
Left ventricular failure:	Age
abnormal left ventricular	Severity of angina
angiogram with hypokinesis,	No. of vessels involved
akinesis, or aneurysm	No. of grafts involved
Ejection fraction <0.20.	Previous Infarction (old)
LVEDP > 18mm Hg	Acute myocardial ischemia
Mitral insufficiency.	
Recent myocardial infarction	
Combined surgical procedures	
Surgical experience and skill	

A high percentage of patients with LMCA stenosis also have a majority of these high and low risk correlates. Table 9 compiles the baseline data of several series of patients with LMCA stenosis of $\geq 50\%$. The average incidence of left ventricular dysfunction associated with this lesion was 76%. This is approximately twice the average incidence of LV dysfunction found among the general CAD population undergoing bypass surgery (57,65,66,80,81). In addition, 79% of patients with LMCA lesions have significant disease of the right coronary artery. About half of the patients in the LMCA subgroup have severe angina (New York Heart Association Class III-IV or "unstable" angina), and about half have had a myocardial infarction prior to angiography and/or surgery. Finding a higher operative mortality for the LMCA subgroup, then, might well be the result of this high frequency among these patients of a number of factors that increase the operative mortality, and in particular the presence of left ventricular dysfunction. It is reasonable to say, however, that regardless of the specific etiology, patients with LMCA lesions have an associated high mortality rate at bypass surgery when compared to the overall group with coronary artery disease.

Evaluation of the incidence of perioperative transmural myocardial infarction occurring during or in the period following bypass procedures have been complicated by several factors in various reported series. As with operative mortality, results depend largely upon patient selection in a particular institution.

Table 9. Incidence of Operative Risk Factors Among Patients with ≥ 50%
LMCA Stenosis

Ref	Investigator	No. of Pts.	LV Dysfunction	Previous MI	Severe Angina	+RCA
14	Cohen and Gorlin	73	<u>></u> 78%	36%		73%
16	Takaro et al	113	66%	56%	62%	83%
18	Lavine et al	30	86%	63%	37%	97%
20	DeMots et al	58		24%	45%	83%
22	Oberman et al	179		39%	65%	86%
25	Talano et al	145	76%		66%	66%
27	Lim et al	141		28%	62%	
28	Zeft et al	56			75%	66%
29	Sung et al	39	90%	57%	80%	85%
31	McConahay et al	176		41%	92%	
32	Campeau et al	311		50%	32%	
TOTAL NO. OF PATIENTS:			400	1120	1248	693
AVERAGE:			76%	43%	59%	79%
σ:			7.4	10.0	19.8	9.2

Abbreviations:

LV dysfunction=the presence of abnormal LV angiogram or EF <0.20, or
LVEDP >18mm Hg, or mitral insufficiency.

Previous MI=history of myocardial infarction

Severe angina=New York Heart Association Class III-IV or "unstable"

+RCA=LMCA stenosis + ≥70% obstruction of RCA

Furthermore, and perhaps more importantly, figures vary according to the method of detection of myocardial infarction employed and the diligence of the search carried out by the investigators (35,70). Assad-Morell and co-workers (82) in assessing the incidence of perioperative transmural myocardial infarction following bypass surgery compared post-operative elevations of serum glutamic oxaloacetic transaminase (SGOT) and creatine phosphokinase (CPK) to the development on serial electrocardiograms (ECG) of new pathologic Q waves (83). Sixty-one of their group of 500 patients were found to have SGOT values of >100 u/liter on the first postoperative day. Only 48 percent (29 patients) of these 60 had ECG evidence of transmural MI, and of the 48 patients with ECG evidence of infarction, only 60% had SGOT values of >100 u/liter on the first postoperative day. Consideration of CPK values did not improve discrimination, and serum enzyme values on the second and third postoperative days demonstrated no correlation to ECG evidence. Alderman and colleagues (84) compared post-operative elevations of CPK, SGOT, and lactic dehydrogenase (LDH) to ECG evidence of transmural MI following bypass surgery in 112 consecutive patients. Despite establishing 90th percentile levels for enzyme values after surgery as an index for suspected infarction, correlation in specific cases to ECG evidence was variable. The authors concluded that non-specific cardiac enzyme testing could not provide a dichotomous separation between patients with and without ECG evidence of infarction. Marlon and Quinn (85) compared results of Technetium-99m pyrophosphate scans with

CPK, SGOT, and LDH testing as well as postoperative serial ECG's in 28 survivors of bypass procedures. They found 50% of the survivors to have positive scans, 89% to have significant enzyme elevations, and only 21% to have new pathological Q waves on serial electrocardiograms.

While quantitation of the isoenzymes of creatine phosphokinase has been used to document acute myocardial infarction in nonsurgical patients (86), limited work has specifically addressed the use of CPK fractionation for detection of perioperative myocardial infarction following bypass procedures. Isoenzyme recognition of acute myocardial necrosis is based on the uniquely high concentration of the CPK-MB molecular form in human cardiac tissue and its absence in normal serum. Dixon et al (87) in 1973 were the first to apply this principle to the recognition of acute myocardial infarction following surgery. They compared post-operative elevations of the CPK-MB isoenzyme in a group of 20 patients undergoing non-cardiac operations and in a group of 100 patients having coronary artery bypass surgery with the appearance of new pathologic Q waves on ECG. Of the 20 patients undergoing noncardiac operations, none demonstrated ECG changes of acute MI, and 1 had an elevated CPK-MB fraction. This patient died during the post-operative period and myocardial infarction was confirmed at autopsy. Of the 100 patients undergoing coronary bypass grafting, 49 had no appearance of CPK-MB, and none of these had new Q waves on ECG. In 21 of the 100, both CPK-MB and new pathologic Q waves on ECG appeared postoperatively. The mean duration of detectable CPK-MB in the

serum of these patients was 31 hours. In the remaining 30 patients CPK-MB was detected without ECG evidence of acute myocardial infarction. O'Rourke and co-workers (88) also found a significant correlation of elevated CPK-MB isoenzyme to new pathologic Q waves on ECG in their 28 patients undergoing bypass surgery. As in the Dixon study (87) a higher percentage of patients had positive CPK-MB results than significant ECG changes. Righetti et al (89) studied 41 patients before and after bypass surgery utilizing serum CPK-MB isoenzyme measurements, Technetium-99m pyrophosphate scans, and the 12-lead ECG. They established an upper limit of "normal" for CPK-MB released after uncomplicated bypass surgery and compared the results of these three techniques. All 6 patients who had new Q waves on electrocardiogram had above-"normal" CPK-MB levels, and 5 of these had positive scans; five patients with "ischemic" ECG's and no new Q waves also had positive scans and high CPK-MB levels; and 6 patients with no ECG changes had high CPK-MB results but negative scans. The authors concluded that: 1.) new Q waves on ECG underestimate the incidence of myocardial damage after coronary artery surgery; 2.) CPK-MB measurements alone overestimate the incidence of infarction; and 3.) A combination of the three techniques provides the best means of detecting myocardial infarction after bypass surgery. This statement represents an accurate summary of the current status of the detection of myocardial infarction occurring during or immediately following bypass surgery. Most workers to date have employed the 12-lead electrocardiogram using the Q

wave criterion to follow their post-operative patients.

In table 7A and 7B are displayed the combined results for occurrence of myocardial infarction in the perioperative period (up to 30 days after surgery) for coronary bypass surgery performed since 1970 in major centers for patients with LMCA lesions and for the general CAD population (14,16,17,22,25,28,30-32,35,57,61,62,64-69). All studies employed the electrocardiographic Q wave criterion for detecting myocardial infarction. As shown in the tables, the LMCA subgroup incurs MI in the perioperative period approximately as frequently as the overall CAD population undergoing bypass surgery, 8 to 10%. We note that this is most likely a low estimate as diligence in looking for infarction was variable among the studies and the method of detection a conservative one. It is also noted that some investigators did not include in their calculations for perioperative infarction those operative deaths that might have infarcted (see tables).

INTRA-AORTIC BALLOON PUMP; BACKGROUND AND PHYSIOLOGIC PRINCIPLES:

To date the intraaortic balloon counterpulsation device (IABP) has been the most frequently used assist unit in the treatment of myocardial ischemia and low-output failure resulting from a variety of clinical disorders (36-44). The first reported clinical usage of the device was by Kantrowitz and co-workers (90), who in 1967 used the IABP to successfully support two patients in cardiogenic shock following myocardial infarction. In the next 2 years several other investigators reported similarly successful results for the improvement and reversal of the clinical shock state following myocardial infarction in small numbers of patients (36,91). These early clinical successes led to rapid growth in the use of the IABP for a wide variety of disorders, and it is now estimated that over 22,000 such devices have been inserted worldwide (37).

Standard procedure for insertion of the IABP is through a Dacron graft anastomosed end-to-side to the femoral artery. The balloon is inflated in synchrony with the electrocardiogram and is timed to begin inflation at aortic valve closure and deflate prior to aortic valve opening (38). This results in two important benefits: augmentation of coronary blood flow and reduction in heart work.

IABP-induced augmentation of aortic root pressure during diastole occurs at a time when coronary vascular resistance is minimal. Coronary perfusion pressure is thereby elevated, resulting in improvement in blood flow and enrichment of oxygen supply to ischemic parenchyma. A number of workers have measured flow in a major patent coronary vessel

following acute ligation of another major coronary vessel and found a 7 to 50% increase with the IABP (92-95). Coronary autoregulation has also been found to influence the degree of IABP augmentation. Powell and associates (95) pointed out that not until total coronary blood flow has been significantly reduced (to less than 50 ml/min/100 grams of left ventricle) during hypotension can the IABP augment flow. A detailed review of the physiologic parameters that influence the degree of augmentation to flow by the IABP exceeds the bounds of this paper, but it is recognized to be a complex interdependence of a number of factors including autoregulation, the extent of obstructive atherosclerotic disease, the size of the ischemic area, the extent of collateralization, and other hemodynamic and mechanical factors (38).

The second benefit supplied by the IABP is reduction in required heart work and consequent reduction in oxygen consumption. The blood displaced by the balloon into the peripheral circulation reduces aortic end-diastolic volume and thereby reduces the impedance to ejection during the next contraction (reduction in "afterload"). Most workers have found a lessening of left ventricular systolic pressure by 4 to 20%, with an average reduction of 15% with the IABP (36,92,96,99). Furthermore, as afterload is reduced, it is predicted that the amount of shortening (or stroke volume) should increase as a result of the force-shortening relationship of the left ventricle (100). Weber and Janicki (38) confirmed these predictions by measuring a 6 to 7% increase in stroke volume during

IABP assistance. This increase in shortening, the authors propose, leads to more complete emptying, a decline in end-systolic and end-diastolic volumes, and thus a reduction in preload. The IABP, then can assist the left ventricle by reducing both preload and afterload.

Despite extensive demonstration of the clinical efficacy of the balloon for improving cardiac performance, limited work has focused on its effect on specific left ventricular hemodynamics and regional wall motion in clinical situations of ischemic heart conditions. This undoubtedly is the result of the infeasibility of performing multiple ventriculograms in critically ill patients. Nichols and associates (101), however, recently studied these parameters using multigated cardiac blood pool imaging (102) in 9 patients with unstable angina and 9 patients with acute myocardial infarction requiring IABP support. They found a significant reduction in end-diastolic and end-systolic volumes with the balloon in both situations of unstable angina and myocardial infarction. In addition, the IABP improved segmental contraction in all 7 unstable angina patients with regional wall motion abnormalities, but not in the 9 patients with acute myocardial infarction. The authors conclude that the IABP enhances contraction of the ischemic but not infarcted myocardium and effectively improves ventricular function by reducing end-diastolic and end-systolic volumes.

Prophylactic Balloon Counterpulsation for Cardiac Surgery

Intraaortic balloon counterpulsation has been used prophylactically for patients with serious left ventricular dysfunction, severe ischemia,

and impending myocardial infarction undergoing cardiac surgery (37,39, 42-44). Feola and colleagues (42) reported an improvement in operative mortality rate for bypass surgery from 8 to 4% in patients with poor left ventricular function (ejection fraction <0.30) when counterpulsation was instituted preoperatively and continued intra-and postoperatively for 2 to 5 days. Others have reported a similar reduction in operative mortality for this subgroup undergoing bypass procedures (37,39).

Increasing use of the IABP has also been reported for patients with unstable angina pectoris or impending myocardial infarction going to surgery for coronary grafting (37,39,103-105), with significant reduction in operative mortality. In addition, a recent article by Cooper et al (44) reported on the routine use of preoperative IABP in 26 patients with left main coronary stenosis. They had no mortality in this group and an 8% incidence of perioperative myocardial infarction. While only minimal description was given of the preoperative risk profile of the group, their results suggest a promising area for more comprehensive evaluation.

Risks of the IABP

While the performance of a cardiac assist device is very important, assessment of associated side effects is of equal concern. Table 10 lists the complications that have been observed in patients on IABP assist in order of potential clinical severity:

Table 10. Complications of the IABP:

<u>Complication</u>	<u>Average incidence in combined studies</u>	<u>References</u>
Aortic damage	2.3%	37, 99, 106, 107
Dissection of wall		
Laceration		
Subadventitial hematoma		
Vascular insufficiency of catheterized limb	3.7%	37, 99, 106, 107
Infection	4.2%	37, 107
Groin wound		
Bacteremia		
Embolic phenomena	1.3%	37, 99, 106
Platelet reduction	(common, but very rare clinical sequelae)	99, 108, 109
Red cell destruction	(minimal)	100
Balloon rupture and gas embolus	(very rare)	37, 100, 106
Ventricular rupture	(not proved)	99, 100, 107

Aortic dissection of varying severity has been reported in 1 to 5 % of patients receiving the IABP in various studies (37,99,101,106,107,108). While most workers report uneventful recovery, death resulting from balloon induced aortic damage has occurred. McEnamy et al reported 6 deaths (0.82%) related to aortic dissection secondary to improper device placement.

Infection of the groin wound and bacteremia have been reported in approximately 3% and 1%, respectively, on the average in reporting centers (37, 107). The vast majority of these complications have been non-fatal.

A frequently encountered complication of intraaortic counterpulsation is vascular insufficiency of variable severity distal to the arteriotomy site of the catheterized limb (37,99,106,107). Scheidt and associates (106) used the AVCO intraaortic balloon in 87 patients with cardiogenic shock and reported distal circulatory problems of varying severity in 13 patients (15%). Two had only transient distal arterial insufficiency which disappeared after removal of the device. Two others required ileo-femoral bypass after the balloon was removed, with good results. One patient had permanent arterial insufficiency of the leg, and two others developed leg neuropathies of variable severity and duration. Six patients died before a final outcome was apparent. Beckman and colleagues (107) reported limb ischemia in 16 of 173 patients (6%) receiving intraaortic balloon counterpulsation (AVCO balloon) as an adjunct to surgical or medical therapy from 1973-1976. Distal arterial insufficiency resolved in 12, resulted in gangrene of the toes in 1, leg gangrene in 2, and was the cause of death in 1 patient. McEnamy and co-workers (37) reported a 1.6% incidence of vascular insufficiency of variable severity in 728 patients receiving the IABP from 1968 to 1976. While there was a 5.7% incidence of femoral thrombosis in this study, all of these patients were treated by local surgical procedures with no resulting cases of limb ischemia. Dunkman and associates (99) since 1972 have been routinely exploring balloon catheterized vessels with a Fogarty catheter at the time of balloon removal, and in so doing have been able to reduce the incidence (and severity) of vascular insufficiency to 2.5%.

Embolic phenomena resulting from balloon-induced thrombosis have been reported in approximately 1 to 5% of patients. Scheidt et al (106) had 1 death attributable to a renal embolus associated with a thrombus on the surface of the balloon in a patient who had not been anticoagulated and the balloon motionless on stand-by for many hours. McEnamy et al (37) reported a 1% incidence of peripheral emboli in their series of 728 patients. Dunkman et al (99) found no clinical evidence of emboli in their series but noted incidentally on post-mortem examination small testicular~~y~~ and renal emboli in 2 patients (5%).

A complication of the IABP that has been consistently cited is a reduction in platelet count, occurring within the first 24 hours. Dunkman et al (99) reported a fall of 50% from prepumping levels in most patients. A return to normal levels occurred during a variable time period following removal of the balloon among these patients. DeLaria (108) and Madras (109) found similar results in animal studies.

While the possibility of balloon rupture and gas embolism is always present, only 1 death has been reported (106), thought to be due to improper insertion of the device leading to rupture. McEnamy and associates reported a non-fatal case of a balloon gas leak among their 728 patients.

A subdivision of IABP related complications into "minor" and "major" categories has been proposed by McEnamy and colleagues (37) according to whether the complication had caused either death, a second surgical procedure, abbreviation of IABP therapy, long-term morbidity, or prolongation of the

hospital stay. Table 11 is a compilation of complications classed in this manner encountered by several groups.

Table 11. Incidence of Complications with the IABP

Ref	Investigator	No. of Pts	Overall Complications rate (%)	Major Complications rate (%)
37	McEnamy et al	728	21.6	8.8
99	Dunkman et al	40	10	0
106	Scheidt et al	87	21.8	8.0
107	<u>Beckman et al</u>	<u>273</u>	<u>13.5</u>	<u>4.0</u>
	TOTAL	1128	19.2% $\sigma=3.9\%$	7.3% $\sigma=2.4\%$

The average overall incidence of complications is 19.2% with a 7.3% incidence of major complication.

While the IABP has successfully influenced patient recovery in many clinically settings, the risk of side effects is indeed non-trivial.

PATIENTS AND METHODS

Data were collected prospectively on 91 consecutive patients shown to have greater than 50% obstruction of the left main coronary artery who underwent aortocoronary bypass grafting at Yale-New Haven Hospital from June 1975 through December 1977.

Diagnostic cardiac catheterization consisted of pressure measurements, cardiac output determination, right anterior oblique left ventriculogram for analysis of regional wall motion (110), mitral regurgitation, and ejection fraction [calculated according to the method of Greene (111)], and selective coronary cinearteriography, all performed by standard techniques. A greater than 50% stenosis of the left main coronary artery and a greater than 70% stenosis for other coronary arteries was considered significant.

Coronary bypass surgery was performed within two weeks following angiography in all patients. All grafts to the left circumflex and right coronary arteries were performed using reversed autogenous saphenous veins. The left anterior descending artery was grafted using the left internal mammary artery (LIMA) in 37 patients, aorto-saphenous bypass (SVG) grafts in 45 patients, and double grafts using SVG and LIMA in 9 patients. Dissection of the left internal mammary artery from the chest wall and proximal anastomoses of saphenous vein grafts were accomplished without cardiopulmonary bypass. Distal anastomoses were performed on full cardiopulmonary bypass using topical hypothermia at 28°C to 30°C with the heart in ventricular fibrillation. Aortic

cross-clamping was used only when a dry field could not be obtained by local occlusion of the coronary artery. Each distal anastomosis was probed near its completion to ensure that the anastomotic communication was wider than the grafted coronary artery. The left ventricle was vented in all patients by a catheter passed through the right superior pulmonary vein or the ventricular apex into the left ventricular cavity. All blood aspirated into the extracorporeal circuit from the vent or cardiac suction lines was filtered through a millipore filter* before being returned to the oxygenator**. Whole blood was transfused only if perfusate hematocrit fell below 25 percent, and serum potassium levels were carefully monitored and appropriately adjusted.

Definition of Variables Studied

Operative mortality was considered to be in-hospital death within 4 weeks of surgery. Perioperative MI was defined as myocardial necrosis occurring within 1 week postoperatively and identified by serial electrocardiograms (ECG's), post-mortem examination, or both. Major operative complication was defined as surgically-related death or perioperative myocardial infarction. All patients had daily standard 12-lead electrocardiograms from the day before surgery until the seventh postoperative day with the first operative tracing obtained upon arrival in

* Swank Micro-Emboli Filter, Pioneer Filter Co., Beaverton, Oregon.

**Temptrol Disposable Blood Oxygenator Model Q100, Bentley Laboratories Inc., Santa Anna, California; or Kolobine Disposable Membrane Oxygenator, Sci-Med, Minneapolis, Minnesota

the Surgical Intensive Care Unit. The criterion for acute myocardial infarction was the development on serial ECG's of new significant pathological Q waves, equivalent to Class I-1 and I-2 of the Minnesota Code (112). New intraventricular conduction defects, new bundle branch blocks, increasing size of previous Q waves, ST segment or T wave changes without new pathological Q waves or elevations of CPK, SGOT, LDH, and CPK-MB isoenzyme were not considered diagnostic of MI. Mortality of perioperative MI was considered to be death up to 4 weeks after coronary surgery.

Statistical Methods:

Contingency table chi-square (χ^2) and multiple logistic regression model were used to analyze the data. A probability value <0.05 was considered statistically significant. When information on a specific clinical characteristic of a patient was not available, that patient was excluded from analysis of the particular variable.

Patient Groupings

Thirty-five patients were treated pre-operatively with intraaortic balloon counterpulsation***, and these patients were classed in this study as Group A. Fifty-six patients did not receive the IABP and were classed as Group B. The individual clinical decision regarding the insertion of an IABP depended largely upon the clinical condition of the patient and

***AVCO Intra-aortic Balloon, Hoffman-LaRoche, Inc., Cranbury, New Jersey.

the availability of an IABP, but maximal effort was made to assist patients with unstable angina with counterpulsation. When used, the IABP was introduced under local anesthesia in the Surgical Intensive Care Unit through the common femoral artery via an end-to-side 10 mm. dacron graft and advanced into the descending thoracic aorta. When difficulties in balloon introduction were encountered or anticipated, a wire-guided central lumen balloon catheter (113) was introduced under direct fluoroscopy and pressure monitoring in the cardiac catheterization laboratory. Details of IABP introduction and management have been previously described (107).

The IABP was removed either at bypass surgery or up to 48 hours postoperatively in the Surgical Intensive Care Unit in all cases.

Demographic Characteristics:

Table 12 displays parameters relating to the past medical history and physical examination of this group of 91 patients with left main stenosis. If a specific parameter was not known for a particular patient that patient was eliminated from consideration for that descriptor. History of congestive heart failure (CHF) was considered positive if the patient had past clinical history of dyspnea on exertion or had physical signs at examination. Family history was considered positive only if ischemic heart disease was present in an immediate family member before age 55. Hypertension was defined as present in the history if the

patient was being treated for hypertension or had repeated systolic pressures above 160mm Hg or diastolic pressures above 95mm Hg during admission. Peripheral vascular disease was considered present if there was a history of intermittent claudication or physical findings of decreased peripheral pulses or bruits. A patient was classed as having a positive smoking history if he smoked cigarettes daily for at least 1 year within 10 years of admission. Angina pectoris was graded according to the New York Heart Association (NYHA) functional classification (114): Class I = minimal limitation of activity - "ordinary" physical activity does not produce symptoms; Class II = slight limitation of ordinary activity - symptoms with severe exertion. Class III = marked limitation of ordinary physical activity - symptoms with mild exertion; Class IV = inability to carry on any physical activity without discomfort - symptoms may occur at rest. The pattern of angina was classed as "stable" if no change in the severity of symptoms was reported within the 6 month period prior to admission "progressive" if anginal symptoms were becoming more frequent or severe (change in NYHA Class), and "unstable" only if the patient experienced chest pain at rest of at least 20 minutes' duration, refractory to medical therapy with β -blockers and nitrates. We point out that this is a relatively rigorous definition of unstable angina corresponding to the "intermediate coronary syndrome", "pre-infarction angina", or "crescendo angina" used by other authors (103,115-118). Patients on propranolol were subdivided according to daily dosages above or below 160mg and according to the method of discontinuation before surgery (abrupt withdrawal= cessation of propranolol without tapering within 24 hours of surgery).

Table 12. Demographic Characteristics: Medical History and Physical Exam

	<u>Total</u>	<u>Group A (IABP)</u>	<u>Group B (no IABP)</u>
No. of Patients	91	35	56
AGE			
<55	34/91 (37%)	10/35 (29%)	24/56 (43%)
>55	57/91 (63%)	25/35 (71%)	32/56 (57%)
SEX			
M	73/91 (80%)	31/35 (89%)	42/56 (75%)
F	18/91 (20%)	4/35 (11%)	14/56 (25%)
Previous MI	37/87 (43%)	16/35 (46%)	21/52 (40%)
H/O CHF	24/87 (28%)	10/35 (29%)	14/52 (27%)
+ Family Hx	54/87 (62%)	22/33 (67%)	32/54 (59%)
H/O Hypertension	29/90 (32%)	10/35 (29%)	19/55 (35%)
Peripheral Vascular Disease	24/91 (26%)	7/35 (20%)	17/56 (30%)
Smoking	58/90 (64%)	21/34 (62%)	37/56 (66%)
ANGINA			
Severity: Class I (NYHA)	2/91 (1%)	0/35 (0%)	2/56 (3%)
Class II	14/91 (15%)	3/35 (9%)	11/56 (20%)
Class III	22/91 (24%)	4/35 (11%)	18/56 (32%)
Class IV	53/91 (58%)	28/35 (80%)	25/56 (45%)
Pattern: Stable	22/91 (24%)	6/35 (17%)	16/56 (29%)
Progressive	52/91 (57%)	16/35 (46%)	36/56 (64%)
Unstable	17/91 (19%)	13/35 (37%)	4/56 (7%)
PROPRANOLOL			
NONE	14/89 (16%)	1/35 (3%)	13/54 (24%)
<160 QD	22/89 (25%)	6/35 (17%)	16/54 (30%)
≥160 QD	53/89 (60%)	28/35 (80%)	25/54 (46%)
PROPRANOLOL TAPERING			
No propranolol	14/75 (19%)	1/35 (3%)	13/40 (32%)
Abrupt withdrawal	6/75 (8%)	1/35 (3%)	5/40 (12%)
Tapered or discontinued >36 hours pre-op on IABP	53/75 (71%)	33/35 (94%)	22/40 (55%)

Abbreviations:

CHF=congestive heart failure

F=female

H/O=history of

Hx=history

It can be seen that the following variables were distributed approximately equally between the 35 Group A and 56 Group B patients: age over 55, sex, history of previous MI, history of congestive heart failure (CHF), positive family history, history of elevated blood pressure,

evidence of peripheral vascular disease, history of smoking, and propranolol dosage and tapering. Sixty-three percent of the population was over 55; 80% were male, 43% had a history of previous MI 28% had symptoms of CHF; 62% had a positive family history; 26% showed signs of peripheral vascular disease; 64% had a positive smoking history; 60% had been on more than 160 mg. propranolol per day, and 8% had propranolol therapy abruptly stopped without tapering before surgery.

Statistically significant differences between the two groups were found only in the severity and pattern of angina pectoris. Eighty percent of Group A patients had New York Heart Association (NYHA) Class IV angina, while only 45% of Group B patients had Class IV Symptoms ($p < 0.05$). Unstable angina was present in 37% of Group A patients compared to 7% of Group B patients ($p < 0.05$).

Similarly, radiologic, hemodynamic, and angiographic data are shown in Table 13.

Table 13. Demographic Characteristics: Chest X-ray and Cardiac Catheterization

	<u>Total</u>	<u>Group A (IABP)</u>	<u>Group B (no IABP)</u>
Cardiac Enlargement	16/91 (18%)	6/35 (17%)	10/56 (18%)
VESSELS DISEASED			
LMCA only	14/91 (15%)	2/35 (6%)	12/56 (21%)
LMCA + RCA	77/91 (85%)	33/35 (94%)	44/56 (79%)
EJECTION FRACTION			
≥ 0.60	39/75 (52%)	14/29 (48%)	25/46 (54%)
< 0.60	36/75 (48%)	15/29 (52%)	21/46 (46%)
LVEDP			
≤ 12 mm Hg	31/84 (37%)	11/34 (32%)	20/50 (40%)
> 12 mm Hg	53/84 (63%)	23/34 (68%)	30/50 (60%)
Mitral Regurgitation	6/81 (7%)	2/35 (6%)	4/46 (9%)
Abnormal Segmental			
wall motion	53/84 (63%)	25/34 (73%)	28/50 (56%)

Abbreviations:

LMCA=left main coronary artery

LVEDP=left ventricular end-diastolic pressure

RCA=right coronary artery

+=positive

A comparable distribution between the two groups can be seen for cardiac enlargement (CT ratio on chest x-ray $>50\%$), abnormal ejection fraction (EF), elevated left ventricular end-diastolic pressure (LVEDP), evidence of mitral regurgitation, presence of triple vessel disease and of abnormal

segmental wall motion. Eighteen percent of the total population had cardiac enlargement; 48% had an EF of <0.60 ; 63% had LVEDP of $> 12\text{mm Hg}$; 7% had evidence of mitral regurgitation; 85% had disease of the right coronary artery (RCA) in addition to the left system; and 63% had abnormal segmental wall motion on left ventriculogram.

Table 14 displays operative data for the group.

Table 14. Operative History

	<u>Total</u>	<u>Group A (IABP)</u>	<u>Group B (no IABP)</u>
NO. OF GRAFTS PERFORMED			
1	1/91 (1%)	0/35 (0%)	1/56 (2%)
2	26/91 (29%)	4/35 (11%)	22/56 (39%)
3	56/91 (62%)	26/35 (74%)	30/56 (54%)
4	7/91 (8%)	4/35 (11%)	3/56 (5%)
DISEASED VESSELS NOT GRAFTED			
All grafted	61/91 (67%)	24/35 (69%)	37/56 (66%)
One diseased vessel not grafted	30/91 (33%)	11/35 (31%)	19/56 (34%)
Specifically: LAD	2/91 (2%)	1/35 (3%)	1/56 (20%)
LCF	21/91 (23%)	6/35 (17%)	15/56 (27%)
RCA	7/91 (8%)	4/35 (11%)	3/56 (5%)
CPB TIME			
≤ 90 min. (")	38/91 (42%)	13/35 (37%)	25/56 (45%)
> 90 min.	53/91 (58%)	22/35 (63%)	31/56 (55%)
ANOXIA TIME			
0	27/91 (30%)	11/35 (31%)	16/56 (29%)
0-30"	27/91 (30%)	8/35 (23%)	19/56 (34%)
31-60"	30/91 (33%)	11/35 (31%)	19/56 (34%)
>60 "	7/91 (8%)	5/35 (14%)	2/56 (4%)

Abbreviations:

LAD=left anterior descending coronary artery

LCF=circumflex coronary artery

RCA=right coronary artery

CPB=cardiopulmonary bypass

An approximately equal distribution of patients receiving the IABP and those not was seen for number of diseased vessels not grafted (incomplete revascularization), cardiopulmonary bypass (CPB) time, anoxia time (aortic cross-clamping), and number of grafted vessels. Sixty-seven percent of the population had complete revascularization; 58% had a CPB time longer than 90 minutes; 41% had anoxia times greater than 20 minutes; and 69% received three or more grafts. No differences in operative parameters were seen between the two groups.

RESULTS

Operative Mortality:

Eight deaths occurred at or within 3 weeks of bypass surgery in the overall group of 91 patients with left main obstruction (9%). Two of these patients were in Group A, one of whom suffered an intra-operative myocardial infarction and could not be weaned from cardiopulmonary bypass, the other of whom had severe left ventricular failure and inability to come off bypass with no evidence of myocardial infarction. Six deaths occurred among Group B patients of whom 3 died in the operating room. Two of these three had evidence of intra-operative infarction while the third suffered severe left ventricular failure, preventing weaning from cardiopulmonary bypass. Two others had evidence of perioperative infarction, succumbing within 2 weeks of surgery to the complications of post-operative cardiogenic shock. The sixth death in Group B was the result of low output left ventricular failure 21 days after surgery in a patient who had no evidence of perioperative myocardial infarction.

An analysis of the incidence of operative death for previously reported or suggested risk factors is displayed in Table 15.

Table 15. Operative Deaths

	Total	Group A (IABP)	Group B (No IABP)
INCIDENCE	8/91 (9%)	2/35 (6%)	6/56 (11%)
AGE			
<55	1/34 (3%)	0/10 (0%)	1/24 (4%)
<u>>55</u>	7/57 (12%)	2/25 (8%)	5/32 (16%)
SEX			
M	5/73 (7%)	2/31 (6%)	3/42 (7%)
F	3/18 (17%)	0/4 (0%)	3/14 (21%)
PREVIOUS MI	2/37 (5%)	1/16 (6%)	1/21 (5%)
h/O CHF	1/24 (4%)	0/10 (0%)	1/14 (7%)
ANGINA			
Severity: NYHA Class I	1/2 (50%)	-	1/2 (50%)
Class II	1/14 (7%)	0/3 (0%)	1/11 (9%)
Class III	2/22 (9%)	0/4 (0%)	2/18 (9%)
Class IV	4/53 (7%)	2/28 (7%)	2/25 (8%)
Pattern: stable	3/22 (14%)	0/6 (0%)	3/16 (19%)
progressive	2/52 (4%)	0/16 (0%)	2/36 (6%)
unstable	3/17 (18%)	2/13 (15%)	1/4 (25%)
PROPRANOLOL			
none	2/14 (14%)	0/1 (0%)	2/13 (15%)
<160mg QD	2/22 (9%)	0/6 (0%)	2/16 (12%)
<u>>160mg QD</u>	4/53 (7%)	2/28 (7%)	2/25 (8%)
PROPRANOLOL TAPERING			
No propranolol	2/14 (14%)	0/1 (0%)	2/13 (15%)
abrupt withdrawal	1/6 (17%)	0/1 (0%)	1/5 (20%)
Tapered or discontinued on IABP 36 hours pre-op	6/55 (11%)	2/33 (6%)	4/22 (18%)
CARDIAC ENLARGEMENT	0/16 (0%)	0/6 (0%)	0/10 (0%)
MITRAL REGURGITATION	0/16 (0%)	0/2 (0%)	0/4 (0%)
ABNORMAL SEGMENTAL WALL MOTION	5/53 (9%)	2/25 (8%)	3/28 (11%)

(Continued)

Table 15. Operative Deaths (continued)

	Total	Group A (IABP)	Group B (No IABP)
EF			
≥ 0.60	5/39 (13%)	1/14 (7%)	4/25 (16%)
< 0.60	2/36 (6%)	1/15 (7%)	1/21 (5%)
LVEDP			
≤ 12 mm Hg	3/31 (10%)	1/11 (9%)	2/20 (10%)
> 12 mm Hg	5/53 (9%)	1/23 (4%)	4/30 (13%)
CPB TIME			
≤ 90 min	0/38 (0%)	0/13 (0%)	0/25 (0%)
> 90 min	8/53 (15%)	2/22 (9%)	6/31 (19%)
ANOXIA TIME			
0	2/27 (7%)	1/11 (9%)	1/16 (6%)
0-30 min	4/27 (15%)	1/8 (12%)	3/19 (16%)
31-60 min	2/30 (7%)	0/11 (0%)	2/19 (11%)
> 60 min	0/7 (0%)	0/5 (0%)	0/2 (0%)
VESSELS DISEASED			
LMCA only (RCA-NL)	0/14 (0%)	0/2 (0%)	0/12 (0%)
LMCA + RCA	8/77 (10%)	2/33 (6%)	6/44 (14%)
NO. OF GRAFTS PERFORMED			
1	0/1 (0%)	-	0/1 (0%)
2	4/26 (15%)	1/4 (25%)	3/22 (14%)
3	4/56 (7%)	1/26 (4%)	3/30 (10%)
≥ 4	0/7 (0%)	0/4 (0%)	0/3 (0%)
DISEASED VESSELS NOT GRAFTED			
All grafted	2/61 (3%)	0/24 (0%)	2/37 (5%)
One diseased vessel not grafted	6/30 (20%)	2/11 (18%)	4/19 (21%)
Specifically: LAD	1/2 (50%)	0/1 (0%)	1/1 (100%)
LCF	4/21 (19%)	1/6 (17%)	3/15 (20%)
RCA	1/7 (14%)	1/4 (25%)	0/3 (0%)
EVIDENCE OF INFARCTION AMONG OPERATIVE DEATHS	5/8 (62%)	1/2 (50%)	4/6 (67%)

Abbreviations: Propranolol=dosage of propranolol before surgical management;
EF=ejection fraction; LVEDP=left ventricular end-diastolic pressure;
NL=normal; LAD=left anterior descending; LCF=left circumflex;
RCA=right coronary artery; CPB=cardiopulmonary bypass
MI=myocardial infarction; h/o=history of; CHF=congestive heart failure

In the overall group we found no significant association of operative mortality with age over 55, sex, severity of pattern of angina pectoris, previous myocardial infarction, history of congestive heart failure, pre-surgical propranolol dosage, propranolol tapering prior to surgery, cardiac enlargement, mitral regurgitation, abnormal segmental wall motion, abnormal ejection fraction, elevated LVEDP, operative anoxia time, or number of grafts performed. A significant association to operative mortality was seen, however, for CPB times of > 90 minutes and for incomplete revascularization ($p < 0.05$). Fifteen percent of patients on CPB for longer than 90 minutes died compared to 0% of those with CPB times of $\leq$ 90 minutes. In addition, 20% of patients with one obstructed vessel not grafted perished, compared to 3% of patients receiving complete revascularization to all diseased vessels. A suggested association to operative mortality was noted for patients with disease of the RCA (triple vessel disease). Ten percent of patients with additional disease of the RCA died compared to 0% of patients with LMCA lesions only.

In the IABP group (Group A) there were 2 operative deaths (2/35, 6%) compared to 6 in the group not receiving the IABP (6/56, 11%). This two fold difference, while suggestive, was not significant when tested statistically by contingency table chi-square analysis. We ran a similar analysis of reported risk factors for operative death against the results in each group. The numbers in Group A were small and no statistically significant associations to mortality could be demonstrated. In Group B,

as in the total population, CPB times of longer than 90 minutes were significantly associated with operative mortality (19% vs 0%, $p<0.05$). Suggested associations to operative death in both groups paralleled the findings in the overall populations for triple vessel disease (Group A: 6% vs 0%, Group B: 14% vs 0%) and incomplete revascularization (Group A: 18% vs 0%, Group B: 21% vs 5%).

Statistical analysis of the interdependence of risk factors and balloon usage was performed to determine if any combination was additive. No combination among the various permutations of factors was found to have an additive association with operative mortality.

Perioperative Myocardial Infarction

Perioperative myocardial infarction occurred in 15% of the total population of 91 patients with left main obstruction. The incidence of perioperative MI for previously reported or suggested risk factors is tabulated in Table 16. There was no association between perioperative infarction and age over 55, sex, severity or pattern of anginal pain, previous myocardial infarction, history of congestive heart failure, presurgical propranolol dosage, propranolol tapering, cardiac enlargement, mitral regurgitation, abnormal segmental wall motion, abnormal ejection fraction, elevated LVEDP, anoxia time, or incomplete revascularization. A significant association was seen between CPB times of >90 minutes ($p<0.05$) and suggested for the presence of triple vessel disease and for more than 3 grafts performed. Twenty-three percent of

Table 16. Patients Sustaining Perioperative Myocardial Infarction

	Total	Group A (IABP)	Group B (No IABP)
INCIDENCE	14/91 (15%)	1/35 (3%)	13/56 (23%)
AGE			
<55	5/34 (15%)	0/10 (0%)	5/24 (21%)
<u>>55</u>	9/57 (16%)	1/25 (4%)	8/32 (25%)
SEX			
M	11/73 (15%)	1/31 (3%)	10/42 (24%)
F	3/18 (17%)	0/4 (0%)	3/14 (21%)
PREVIOUS MI	3/37 (8%)	1/16 (6%)	2/21 (10%)
h/o CHF	1/24 (4%)	0/10 (0%)	1/14 (7%)
ANGINA			
Severity: NYHA Class I	0/2 (0%)	-	0/2 (0%)
Class II	4/14 (29%)	0/3 (0%)	4/11 (36%)
Class III	3/22 (14%)	0/4 (0%)	3/18 (17%)
Class IV	7/53 (13%)	1/28 (4%)	6/25 (24%)
Pattern: stable	5/22 (23%)	0/6 (0%)	5/16 (31%)
progressive	8/52 (15%)	1/16 (6%)	7/36 (19%)
unstable	1/17 (6%)	0/13 (0%)	1/4 (25%)
PROPRANOLOL			
None	4/14 (29%)	0/1 (0%)	4/13 (31%)
<160 QD	3/22 (14%)	0/6 (0%)	3/16 (19%)
<u>>160 QD</u>	7/53 (13%)	1/28 (4%)	6/25 (25%)
PROPRANOLOL TAPERING			
No propranolol	4/14 (29%)	0/1 (0%)	4/13 (31%)
Abrupt withdrawal	0/6 (0%)	0/1 (0%)	0/5 (0%)
Tapered or discontinued on IABP 36 hrs. pre-op.	7/55 (13%)	1/33 (3%)	6/22 (27%)
CARDIAC ENLARGEMENT	0/16 (0%)	0/6 (0%)	0/10 (0%)
MITRAL REGURGITATION	0/6 (0%)	0/2 (0%)	0/4 (0%)
ABNORMAL SEGMENTAL WALL MOTION	6/53 (11%)	1/25 (4%)	5/28 (18%)
EJECTION FRACTION			
<u>≥ 0.60</u>	7/39 (18%)	1/14 (7%)	6/25 (24%)
< 0.60	5/36 (14%)	0/15 (0%)	5/21 (24%)

(continued)

Table 16. Patients Sustaining Perioperative Myocardial Infarction. (continued)

	<u>Total</u>	<u>Group A (IABP)</u>	<u>Group B (No IABP)</u>
LVEDP			
≤ 12	6/31 (19%)	1/11 (9%)	5/20 (25%)
> 12	7/53 (13%)	0/23 (0%)	7/30 (23%)
CPB TIME			
$\leq 90''$	2/38 (5%)	0/13 (0%)	2/25 (8%)
$> 90''$	12/53 (23%)	1/22 (5%)	11/31 (35%)
ANOXIA TIME			
0	3/27 (11%)	0/11 (0%)	3/16 (19%)
0-30''	4/27 (15%)	1/8 (13%)	3/19 (16%)
31-60''	6/30 (20%)	0/11 (0%)	6/19 (32%)
$> 60''$	1/7 (14%)	0/5 (0%)	1/2 (50%)
VESSELS DISEASED			
LMCA (RCA-NL)	1/14 (7%)	0/2 (0%)	1/12 (8%)
LMCA+RCA	13/77 (17%)	1/33 (3%)	12/44 (27%)
NO. OF GRAFTS PERFORMED			
1	0/1 (0%)	-	0/1 (0%)
2	5/26 (19%)	1/4 (25%)	4/22 (18%)
3	7/56 (12%)	0/26 (0%)	7/30 (23%)
≥ 4	2/7 (29%)	0/4 (0%)	2/3 (67%)
DISEASED VESSELS NOT GRAFTED			
All grafted	9/61 (13%)	0/24 (0%)	8/37 (22%)
One diseased vessel not grafted	6/30 (20%)	1/11 (9%)	5/19 (26%)
Specifically: LAD	1/2 (50%)	0/1 (0%)	1/1 (100%)
LCF	4/21 (19%)	1/6 (17%)	3/15 (20%)
RCA	1/7 (14%)	0/4 (0%)	1/3 (33%)

Abbreviations: LAD=left anterior descending; LCF=circumflex coronary artery; LMCA=left main coronary artery; LVEDP=left ventricular end-diastolic pressure; NL=normal; RCA=right coronary artery MI=myocardial infarction; h/o=history of; CHF=congestive heart failure

patients with prolonged CPB time infarcted compared to only 5% of those with CPB times of <90 minutes ($p<0.05$). Among patients with triple vessel disease there was a 17% incidence of perioperative MI compared with 7% among patients with LMCA obstruction only. Furthermore, twenty-nine percent of patients receiving 4 or more grafts infarcted compared to 12% with less than 4 grafts.

Among the 35 patients in Group A there was only 1 perioperative infarction (3%) compared to 13 in the group not receiving the IABP (13/56, 23%), $p<0.05$. We again analyzed the results in each group for perioperative infarction and found a significant association in Group B with CPB times of >90 minutes ($p<0.05$). In Group B greater than 3 grafts performed was a suggested risk for perioperative MI (67% vs 20%), as was the presence of triple vessel disease (27% vs 8%). The numbers in Group A were too small for quantitative analysis, but were qualitatively consistent with the findings in Group B and the overall populations.

We again examined the interdependence of risk factors and IABP usage to determine the presence of any additive properties. Table 17 displays data showing an additive effect for the combination of triple vessel disease and not using the IABP and for the combination of prolonged CPB time and not using the balloon.

Table 17. Perioperative Myocardial Infarction

	<u>Patients with IABP Infarcting</u>	<u>Patients without IABP Infarcting</u>	<u>p Value</u>
VESSELS DISEASED			
LMCA only	0/2 (0%)	1/12 (8%)	NS
LMCA + RCA	1/33 (3%)	12/44 (27%)	<0.05
CPB TIME			
≤ 90 min	0/13 (0%)	2/25 (8%)	NS
> 90 min	1/22 (5%)	11/31 (35%)	<0.05

Abbreviations: LMCA=left main coronary artery; IABP=intraaortic balloon pump;
CPB=cardiopulmonary bypass; RCA=right coronary artery;
NS=not significant

The absence of triple vessel disease in patients receiving the IABP yielded a 0% infarction rate, while not using the balloon in the presence of triple vessel disease produced a 27% incidence of infarction. Similarly, 0% of patients receiving the balloon with CPB times shorter than 90 minutes suffered perioperative infarction compared to 35% of patients not counterpulsated with prolonged CPB times.

Table 18 delineates the location of detected perioperative infarctions and the relationship to nongrafted diseased coronary vessels. As noted

above, no significant correlation was found between incomplete revascularization and occurrence of transmural myocardial infarction in the perioperative period. Specific correlations, however, were seen between location of infarcts and particular obstructed vessels not grafted. Of 2 patients not receiving an LAD graft, one suffered an antero-septal infarction. Of 21 patients not receiving a LCFX graft, 2 infarcted laterally, 1 inferiorly, and 1 posteriorly. These areas approximated the regions supplied by the LCFX in the particular patients. The remaining 17 patients did not sustain detectable (on ECG) transmural infarctions. The one patient with detectable transmural MI of the 7 with non-grafted obstructed right coronary arteries infarcted inferiorly. The mortality of perioperative infarction was 36% (5/14), while patients not sustaining an MI had an operative mortality of 3.9% (3/77).

Table 18. Characterization of Infarcts

<u>Location</u>	<u>No. of Pts.</u>	<u>Pt. Group</u>	<u>Operative Death?</u>	<u>Diseased Vessels All Grafted</u>	<u>LAD</u>	<u>LCFX</u>	<u>Not Grafted RCA</u>
ANTERO-SEPTAL	2		2				
Specifically:							
	1	B	YES	+			
	1	B	YES		+		
INFERIOR	7		0				
Specifically:							
	5	B	NO	+			
	1	B	NO			+	
	1	B	NO				+
LATERAL	3		2				
Specifically:							
	1	A	YES				+
	1	B	YES				+
	1	B	NO	+			
POSTERIOR	2		1				
Specifically:							
	1	B	NO	+			
	<u>1</u>	<u>B</u>	<u>YES</u>	<u> </u>	<u> </u>	<u>+</u>	<u> </u>
TOTALS:	14	13B 1A	5	8	1	4	1

Abbreviations: LAD=left anterior descending; LCFX=left circumflex;
RCA=right coronary artery; +=not grafted.

Major Operative Complications; Death or MI

Data on surgical mortality and infarction were combined to determine if the IABP had an effect on the overall rate of major complications, which we defined as death or myocardial infarction in the perioperative period, in patients with LMCA obstruction undergoing bypass surgery. These results are shown in Table 19. There were 17 major complications in the overall group of 91 patients (18%), with 2 occurring among the 35 Group A patients (6%), and 15 among the 56 Group B patients (27%). This represents a statistically significant difference between the two groups ($p < 0.05$). As with incidence of operative deaths and infarctions, CPB time was significantly correlated with the occurrence of a major complication ($p < 0.05$). Twenty-eight percent of patients with CPB times longer than 90 minutes suffered major complications compared to 5% of patients with shorter CPB times. No other statistically significant associations were found, but suggested correlations were the presence of triple vessel disease (21% vs 7%) and incomplete revascularization (27% vs 15%). The results in each group parallel those of the overall population.

Interdependence of the use of the IABP with specific risk factors was examined for the occurrence of major complications, and positive results are listed in Table 20.

Table 19. Major Operative Complications: Death or Myocardial Infarction

	Total	Group A (IABP)	Group B (No IABP)
INCIDENCE	17/91 (18%)	2/35 (6%)	15/56 (27%)
AGE			
<55	5/34 (15%)	0/10 (0%)	5/24 (21%)
≥55	12/57 (21%)	2/25 (8%)	10/32 (31%)
SEX			
M	12/73 (16%)	2/31 (6%)	10/42 (24%)
F	5/18 (28%)	0/4 (0%)	5/14 (36%)
PREVIOUS MI	4/37 (11%)	1/16 (6%)	3/21 (14%)
H/O CHF	3/24 (12%)	0/10 (0%)	3/14 (21%)
ANGINA			
Severity: NYHA Class I	1/2 (50%)	-	1/2 (50%)
Class II	4/14 (29%)	0/3 (0%)	4/11 (36%)
Class III	4/22 (18%)	0/4 (0%)	4/18 (22%)
Class IV	8/53 (15%)	2/28 (7%)	6/25 (24%)
Pattern: stable	5/22 (23%)	0/6 (0%)	5/16 (31%)
progressive	9/52 (17%)	0/16 (0%)	9/36 (25%)
unstable	3/17 (18%)	2/13 (15%)	1/4 (25%)
PROPRANOLOL			
none	6/14 (43%)	0/1 (0%)	6/13 (46%)
<160mg QD	3/22 (14%)	0/6 (0%)	3/16 (19%)
≥160mg QD	7/53 (13%)	2/28 (7%)	5/25 (20%)
PROPRANOLOL TAPERING			
no propranolol	6/14 (43%)	0/1 (0%)	6/13 (46%)
abrupt withdrawal	1/6 (17%)	0/1 (0%)	1/5 (20%)
tapered or discontinued on IABP 36 hours pre-op	10/55 (18%)	2/33 (6%)	8/22 (36%)
CARDIAC ENLARGEMENT	0/16 (0%)	0/6 (0%)	0/10 (0%)
MITRAL REGURGITATION	0/6 (0%)	0/2 (0%)	0/4 (0%)
ABNORMAL SEGMENTAL WALL MOTION	8/53 (15%)	2/25 (8%)	6/28 (21%)
(continued)			

Table 19. Major Operative Complications: Death or Myocardial Infarction
(continued)

	Total	Group A (IABP)	Group B (No IABP)
EF			
≥ 0.60	9/39 (23%)	1/14 (7%)	8/25 (32%)
< 0.60	4/36 (11%)	1/15 (7%)	3/21 (14%)
LVEDP			
≤ 12 mm Hg	7/31 (23%)	1/11 (9%)	6/20 (30%)
> 12 mm Hg	9/53 (17%)	1/23 (4%)	8/30 (27%)
CPB TIME			
≤ 90 min	2/38 (5%)	0/13 (0%)	2/25 (8%)
> 90 min	15/53 (28%)	2/22 (9%)	13/31 (42%)
ANOXIA TIME			
0	4/27 (15%)	1/11 (9%)	3/16 (19%)
0-30 min	5/27 (18%)	1/8 (12%)	4/19 (21%)
31-60 min	7/30 (23%)	0/11 (0%)	7/18 (37%)
> 60 min	1/7 (14%)	0/5 (0%)	1/2 (50%)
VESSELS DISEASED			
LMCA (RCA-NL)	1/14 (7%)	0/2 (0%)	1/12 (8%)
LMCA+RCA	16/77 (21%)	2/33 (6%)	14/44 (32%)
NO. OF GRAFTS PERFORMED			
1	0/1 (0%)	-	0/1 (0%)
2	6/26 (23%)	1/4 (25%)	5/22 (23%)
3	9/56 (16%)	1/26 (4%)	8/30 (27%)
≥ 4	2/7 (29%)	0/4 (0%)	2/3 (67%)
DISEASED VESSELS NOT GRAFTED			
All grafted	9/61 (15%)	0/24 (0%)	9/37 (24%)
One diseased vessel not grafted	8/30 (27%)	2/11 (18%)	6/19 (31%)
Specifically: LAD	1/2 (50%)	0/1 (0%)	1/1 (100%)
LCF	5/21 (24%)	1/6 (17%)	4/15 (27%)
RCA	2/7 (29%)	1/4 (25%)	1/3 (33%)

Table 20. Major Operative Complications (Death on MI)

	<u>Patients with IABP with Major Complications</u>	<u>Patients without IABP with Major Complications</u>	<u>P Value</u>
VESSELS DISEASED			
LMCA only	0/2 (0%)	1/12 (8%)	NS
LMCA+RCA	2/33 (8%)	14/44 (32%)	<0.05
CPB TIME			
<u><</u> 90 min	0/13 (0%)	2/25 (8%)	<0.10
>90 min	2/22 (9%)	13/31 (42%)	<0.05
AGE			
<55	0/10 (0%)	5/24 (21%)	NS
<u>></u> 55	2/25 (8%)	10/32 (31%)	<0.10

NS=not significant, with p value $>.10$ by χ^2 analysis.

An additive effect for risk of incurring a major operative complication was seen in patients with triple vessel disease not counterpulsated (32%) compared to patients with only LMCA obstruction on preoperative counterpulsation (0%). Similarly, patients with prolonged CPB times not on preoperative counterpulsation had a significantly higher incidence of major complication than patients with shorter CPB times receiving the IABP (42% vs 0%). The data also suggested an additive relationship to major

complications for age over 55 and not using the balloon. Thirty-one percent of patients over 55 who were not counterpulsated sustained a major complication at surgery compared to 0% of patients under 55 who were counterpulsated. No other combinations demonstrated or suggested additive risk properties.

Side Effects of IABP Placement or Attempted Placement

In addition to the 35 successful preoperative insertions of the IABP there were 4 unsuccessful attempts and 9 successful intra-or post-operative placements. In 3 of the unsuccessful approaches the IABP could not be advanced beyond the bifurcation of the abdominal aorta and was withdrawn without detectable complication. The fourth led to an aortic dissection that was recognized immediately, and the balloon-catheter withdrawn. No complications or further corrective procedure was necessary in this patient. No cases of arterial insufficiency were noted, and there were 2 post-operative groin infections. The overall complication rate was 6%, 3/48 (Table 21), and in the terminology of McEnamy et al (37), there were no "major" complications reported.

Table 21. Complications of IABP Placement or Attempted Placement

IABP INSERTION:

Pre-op	35	-	Group A
Intra-or Post-op	9	-	Group B
Unsucessful Attempts	4		

COMPLICATIONS

Arterial insufficiency	0/48	(0%)
Aortic dissection	1/48	(2%)
Infection (groin)	<u>2/48</u>	<u>(4%)</u>
TOTAL	3/48	(6%)

DISCUSSION

Discussion of Patients and Methods

This study reports on 91 consecutive patients with $\geq 50\%$ obstruction of the left main coronary artery undergoing bypass surgery at Yale-New Haven Hospital from June 1975 through December 1977. The frequency of baseline parameters for our group was consistent with that of other reports of patients going to bypass surgery with LMCA stenosis (14,16,18, 20,22,25,27-29,31,32).

Thirty-five patients in whom intraaortic balloon counterpulsation was instituted prior to surgery comprised Group A, and 56 patients who did not receive the IABP preoperatively comprised Group B. We recognize that biasing occurred in our groupings as a result of the clinical decision by the surgeon or cardiologist to insert a balloon. While in many cases the finding of a LMCA lesion alone was judged sufficient criterion for preoperative counterpulsation, maximal effort was indeed made to assist those patients with more severe clinical angina. A detailed analysis of demographic, clinical, hemodynamic, and operative descriptors was made to delineate the specifics of possible biasing. A significant difference between the groups was found only for the severity and pattern of anginal pain with a greater proportion of Group A patients having NHYA Class IV symptoms (80% vs 45%) and unstable angina (37% vs 7%). All other parameters were found in parallel distribution in the two groups.

Diagnostic cardiac catheterization and calculations of hemodynamic parameters were performed by standard techniques. While surgical skill and specific technical details are surgeon-dependent, insertion of the

IABP and bypass grafting in this study were performed using standard procedures, with the exception of the method of myocardial preservation employed during completion of distal anastomoses of grafts. This phase of the procedure requires, ideally, a still and relaxed heart for a short period of time. In this series, performed from July 1975 through December 1977, surgical teams used perfusion hypothermia at 28°C to 30°C with the heart in ventricular fibrillation. Numerous methods of cardiac arrest (cardioplegia) in diastole have been employed in experimental and clinical work at various levels of preservation of coronary perfusion. These include profound hypothermia, ischemic-arrest, potassium-induced arrest, procaine arrest, Verapamil induced arrest, and combinations of these (119-125).

Extensive and detailed investigations have attempted to characterize metabolic, ultra-structural, and functional results using various methods of cardioplegia. While questions still remain regarding the superiority of one agent of arrest over another, as well as specific variables within each method, certain conclusions appear consistent in the literature. Infusions of various aqueous solutions into the coronary tree just prior to the onset of ischemia are "trapped" in the coronary vasculature for the duration of the ischemic period (120,124). Effectiveness of protection during ischemia, then, can be resolved into two distinct components: rapidity of induction of cardiac arrest and ability of a particular agent or solution to combat the deleterious changes that occur with tissue ischemia (119,120,122-126). Although the onset of myocardial ischemia is

accompanied by an immediate reduction in contractile activity, this is not complete, and considerable contraction also occurs periodically during ischemia (124). Cardioplegic agents that produce instantaneous cardiac arrest, and thereby conserve cellular energy supplies thus, have a major protective effect. On a cellular level, decreasing the extent of myocardial injury is dependent upon the preservation of cellular stores of adenosine triphosphate (ATP) and creatine phosphate (CP), and upon the maintenance of intracellular ion concentrations in order to preserve the functional integrity of myocardial cells (119,120,122,125).

Topical hypothermia, the method used in this study, protects the myocardium through its ability to reduce metabolic rate, energy consumption, and rate of degrad^{-ative} processes (124,126). Several investigators have found, however, that the addition of procaine or potassium to topical hypothermic solutions can increase functional recovery of the heart at extended ischemic times (120,126,127). This is most likely the result of more rapid induction of arrest and protection of intracellular ion losses during ischemia. Other workers have investigated the effect of combinations of cardioplegic agents on myocardial tolerance to ischemic arrest. Hearse and colleagues (124) through experiments with the working rat heart formulated a solution containing potassium, procaine, ATP, and CP, that minimized myocardial cellular damage for prolonged periods of ischemia. Robb-Nicholson and associates (125), alternatively, reported on the effects of the calcium antagonist Verapamil (ipraveratril) in the rat heart model as a cardioplegic

and protective agent. By blocking calcium ion flux across the sarcolemmal membrane, Verapamil can decrease myocardial oxygen consumption and exert a negative inotropic effect (128,129,130). Comparing to potassium-induced arrest, they reported that the metabolic and physiologic effects of verapamil lasted 20 minutes longer than potassium during ischemia, all other parameters being equal.

It is not possible to formulate a conclusion regarding optimal methodology of cardiac protection during ischemic aspects of the bypass procedure, as research in this area is still extremely active. We note in regard to our series of patients that the method of myocardial preservation employed during ischemia at the time of their surgery was probably not optimal by current standards, and may bear some consequences on the results obtained. This method, however, was consistent with that employed by most workers at that time.

Discussion of Results

The overall operative mortality in our series was 9% (8/91). This was slightly higher than, but comparable to the average results of combined studies listed in Table 7A of 6.6% (14,16,17,22,25,28-32,35) for bypass surgery performed since 1970 for LMCA stenosis. Of note in our results was the high correlation of intra-operative myocardial infarction to death. Five of the 8 operative deaths had suffered intra-operative infarctions (63%).

Of previously reported risk factors for operative mortality in coronary bypass procedures we found statistically significant correlations in this series of LMCA patients only to incomplete revascularization and prolonged CPB time. Abnormal left ventricular angiogram, abnormal ejection fraction, elevated LVEDP, mitral insufficiency, previous myocardial infarction, history of congestive heart failure, age, severity of angina and the number of grafts performed demonstrated no association with increased mortality. The presence of triple vessel disease, however, was a suggested correlate, with 10% of patients with additional disease of the RCA succumbing at surgery compared to 0% of patients with LMCA lesions only. As noted, significant correlations to increased operative mortality were seen for two operative parameters: prolonged CPB time and incomplete revascularization. Other investigators have reported similar findings (34,58,72,77,131,132). Wiles and associates (34) and Ruel et al (131) found a significant increase in operative mortality among CAD patients with triple vessel disease. Oldham (58), Effler (72) and their colleagues and Manley and Johnson (77), however, found no important difference in operative mortality related to the number of vessels involved. Our data were in between, suggesting a possible influence of lesser importance of 3 vessel involvement on operative mortality. Moreover, our finding that incomplete revascularization was significantly associated with increased operative risk has been noted by other workers as well. Oldham and colleagues (58) found an 8% operative mortality in 140 patients in

whom the number of bypass grafts equaled the number of vessels involved, compared with 14% mortality among 128 patients in whom the number of grafts was less than the number of vessels involved ($p < 0.05$). Manley and Johnson (77) and Hammond and Poirier (132) found similar results.

No studies have specifically looked at the correlation of CPB time and operative mortality (though this association has been made for incidence of perioperative MI-vide infra) . Prolonged CPB time can result from difficult anastomoses in severely atherosclerotic coronaries, surgical method and experience, or a combination of these. Increased operative mortality associated with prolonged bypass times may be the result of these factors or other considerations such as hemodynamic, metabolic, or cellular changes that may occur during bypass. We note the association of prolonged CPB and increased mortality and suggest that, when possible, minimalization of the time on cardiopulmonary bypass may positively influence results for operative mortality.

Comparison of the incidence of operative death between the group receiving counterpulsation prior to surgery (Group A) and the group not counterpulsated yielded a non-significant, but suggestive, improvement in operative mortality among assisted patients (11% vs 6%). We are cognizant that, in this comparison, the biasing in the IABP group toward a greater proportion of patients with more severe clinical angina may have influenced the results. We can speculate that if severity of symptoms is indeed an operative risk, as previously reported (71), a greater disparity in results might have been found between the groups.

The data in this series, however, do not substantiate such a claim. Cooper and associates (44) reported improvement in operative mortality rate among patients with left main lesions routinely assisted with counterpulsation before bypass surgery. While their numbers were small (26 patients) and no comparative grouping analyzed, their results were also suggestive of a benefit of the IABP in patients with LMCA obstruction going to bypass surgery. Garcia and colleagues (30) reported on the use of preoperative balloon counterpulsation for bypass grafting in 13 patients with LMCA disease and compared results to 5 patients with a similar risk profile not receiving balloon assist. Three of their 5 patients (60%) not counterpulsated had hypotensive episodes and cardiac arrest prior to the institution of cardiopulmonary bypass, of whom 2 died (40% mortality). All of their assisted patients had uneventful operations and were "long-term" survivors (2 month follow-up), 0% mortality. Their results were statistically significant ($p < 0.05$), though numbers were small.

Transmural perioperative myocardial infarction was detected by Q wave ECG criteria in 15% of our overall sample. This was higher than results reported by other workers since 1970, which ranged from 6.9 to 12.3%, with a mean of 8.0% (16,17,22). Several factors may play a role in this finding of a higher rate of perioperative MI. As noted above, results depend largely upon the diligence of search for MI following surgery. Studies designed specifically to look for perioperative infarction in bypass surgery report a 10.7 to 30% (average=20.4%) incidence

(82,84,85,88,89,133-135) compared to 3.9 to 17% (average=8.4%) reported by workers concentrating on operative mortality (59,66,68,75,81,136,138). Furthermore, varying degrees of patient selection and heterogeneity of population groups makes comparison among results from various centers difficult. Finally, differing experience of surgical teams, variation in technique, and in particular, different methods of myocardial preservation employed during ischemic phases of the operation can influence results.

There was no correlation in our series of perioperative infarction to preoperative clinical presentation, hemodynamic factors such as elevated LVEDP and abnormal ejection fraction, abnormalities of contraction, nor to incomplete revascularization or time of aortic cross-clamping. A significant association to perioperative MI was found in patients with prolonged CPB times and suggested for the presence of triple vessel disease and for more than 3 grafts performed. Several investigators have noted similar results for prolonged bypass time, triple vessel disease, and the number of grafts performed (34,35,138).

Our findings differed from those of Brewer et al (138), but concurred with others (34,35) in that severity and pattern of anginal pain was not related to the frequency of perioperative MI in the overall group. We also found no association of infarction with incomplete revascularization, in contrast to the results of others (134,138). We did find, however, a correlation between the location of detected infarcts and specific obstructed vessels not receiving a graft.

The mortality of perioperative myocardial infarction was 36 percent in this series, while patients not sustaining infarction at surgery had a mortality of 3.9%. This high rate demonstrates the malignant nature of perioperative infarction among patients with left main disease and is in concurrence with recent reports (34,35,61,139).

While Group A (IABP) had a greater proportion of patients with more severe clinical angina, this group had a significantly lower incidence of perioperative MI than the unassisted group (3% vs 23%, $p < 0.05$). Few studies have specifically addressed the effect of counterpulsation on infarction during bypass surgery for LMCA disease. Feola and colleagues (42), however, reported a reduction in incidence of perioperative MI using the IABP on CAD patients with poor left ventricular function. They found a 30.4% rate of infarction in the unassisted group and only 4% in the assisted group. Garcia and associates (30) had no perioperative infarctions among their 13 patients with LMCA stenosis receiving preoperative counterpulsation. While their unassisted cohort of 5 patients did poorly at surgery (2 deaths), the authors did not report on evidence of MI in that group. Cooper (44) and Gunstensen (140) and colleagues who used the IABP in small series of LMCA patients did not report on the incidence of perioperative MI incurred.

An additive effect for increased risk of perioperative MI was demonstrated in patients with triple vessel disease not assisted with the balloon. A similar additive property was shown for prolonged CPB time and non-assistance with the IABP.

Results of perioperative infarction and operative death were combined to determine the overall risk of major complications. Eighteen percent of the 91 patients in the overall group sustained a major complication, with an incidence in the assisted group of 6% and in the unassisted group of 27%. This difference was statistically significant and suggests a balloon-mediated benefit for patients with LMCA disease going to bypass surgery. As in the case of operative death, the overall group and each subgroup had an association to major complication for prolonged CPB time and a suggested correlation for the presence of triple vessel disease and incomplete revascularization. Major complications were particularly prevalent among unassisted patients with triple vessel disease and among unassisted patients with prolonged bypass times. The data also suggested an additive risk for not counterpulsating patients over the age of 55 for the incurrence of a major complication at bypass surgery.

Our series of 48 attempts at IABP placement yielded a complication rate of only 6%, with no "major" complications, as defined by McEnamy et al (37). This is a significantly lower incidence than that reported by most workers, who in combined studies of 1128 balloon placements averaged 18.2% overall complication rate, with 7.3% incidence of "major" complication (37,97,104,105).

Discussion of the IABP

Intra-aortic balloon counterpulsation aids the ischemic myocardium by enriching the supply of oxygen through augmentation of coronary blood

flow and by reducing work requirements of the heart. The resulting improvement in balance between myocardial oxygen supply and demand can be of critical importance in situations of acute myocardial ischemia and left ventricular failure.

Several phases of coronary bypass operations may be associated with significant changes in oxygen supply to the myocardium. Induction of anesthesia is perhaps the most critical facet of the procedure in patients with severely compromised coronary blood flow (23,28,24,44,47, 141). Fluctuations in blood pressure during induction and in the period before institution of cardiopulmonary bypass can result in critical reductions in the myocardial oxygen supply/demand ratio. Cohen et al (47) reported in their series of 17 LMCA patients one anesthetic death due to refractory hypotension and ventricular fibrillation during induction. Zeft et al (28) noted the frequent occurrence of hypotension and serious arrhythmias in patients with left main obstruction during anesthetic induction, and recommended institution of full cardiopulmonary bypass as quickly as possible after anesthesia is achieved. Garcia (23), Cooper (44), and Urschel (141) and ^{their} colleagues similarly recognized a marked lability in blood pressure in patients with left main obstruction during anesthetic induction and operation prior to cardiopulmonary bypass.

On a theoretical level, then, the intra-aortic balloon represents an effective support modality for patients with left main lesions during the early delicate phases of bypass surgical procedures. On a clinical level, our results substantiate its beneficial effect for bypass surgery

in this group of patients. Opinions differ at this point regarding the routine use of counterpulsation for surgical patients with LMCA obstruction. Cooper et al (44) were impressed with their results of 0% mortality among 26 LMCA patients routinely assisted prior to surgery, and implied they would continue the usage of the IABP in all patients with LMCA disease. Garcia and associated (30), who also had good results with counterpulsation, currently recommend elective preoperative balloon support in "highly unstable patients with coronary artery disease considered to be poor surgical risks". The meaning of this criterion is unclear, particularly in light of the fact that clinical severity of symptoms has not been strongly associated with operative mortality or infarction. Feola and colleagues (42) suggest peroperative counterpulsation for patients with poor left ventricular function as an adjunct for reducing surgical mortality. McEnamy and co-workers, in recognizing a high rate of complications resulting from balloon placement in most centers, advocate weighing the risk against potential benefit in individual patients, specifically not subscribing to routine counterpulsation for left main patients.

Complications resulting from balloon placements occurred in a relatively low incidence (6.6%, all "minor") in our series. While possible side effects of therapy must always be weighed against potential benefits, our data are highly suggestive of improved surgical results with preoperative institution of intra-aortic counterpulsation for patients with significant left main coronary obstruction. In the setting of

additional disease of the right coronary artery, or if prolonged cardio-pulmonary bypass time is anticipated, it is even more likely that pre-operative assistance with the IABP can reduce the risk of perioperative death or myocardial infarction.

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